贈呈

韓國考古

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서울大學校 文理科大學
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高靈壁畵古墳調査報告

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發見 및 調査

高靈郡高靈邑古衙洞二洞에 있는 이 壁畵古墳에 關해서 報告者가 처음 뉴스를 들은 것은 1963年 10月이며 報告者는 11月 3日 現地를 調査하여 그것이 이미 盜掘된 壁畵古墳임을 確認하고 다시 11月 23日부터 12月 3日까지에 그 內部를 精査하고 撮影 및 記錄을 하였다.

이 古墳은 玄室北壁上部 天井과 接하는 部位에 구멍을 뚫고 들어간 盜掘者에 依해 內部는 遺物이 없고 또 多年間의 壁面 灰칠 脫落으로 壁畵의 殘存한 部分이 매우 적었으나 그래도 羨道天井石下面에 그려진 蓮花文은 鮮明한 色彩로 남아 있어 11月 3日 이를 實査한 筆者를 感嘆케 하였으나 이 發見이 報道된 뒤의 여러 來訪者들의 不注意한 行動으로 그나마 남아있는 壁畵가 촛불로 타는 등 損傷이 많았으며 또 羨門에 木扉를 해단은 應急的인 保護措置가 도리어 禍가 되어 畵面이 乾燥하여 적지않은 變色을 招來하였다.

位 置

古墳이 있는 古衙二洞은 俗稱 致士里라고 불리우며 高靈邑에서 南方 約 1.5粁, 洛東江의 支流인 會川의 極히 上流(大伽川)가 部落前方을 흐르고 있다. 古墳은 이 部落뒷山(標高 160m)에 있으며 封土위에 서면 南쪽, 東쪽으로 大伽川과 平野가 展開된다. 이 古墳 左右에도 各各 古墳이 一基식 있고 그 西南쪽 臺地에도 數基가 있다. 이 壁畵古墳의 바로 北쪽에 붙어 있는 一基는 그後 64年에 慶北大學校에서 發掘하였는데 東向한 方形石室의 東壁中央에 羨門이 뚫린 石室墳이며 壁畵는 없었고 亦是 盜掘되었고 天井은 全部 落下되어 있었다(金英夏 尹容鎭「仁同, 高靈古墳 發掘調査報告」1966年)

構 造

封 土

現在 남아 있는 封土는 東西 約 22m, 南北 約 20m 이며 高는 傾斜面에 築造된 關係로

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前面에서는 7m이고 後面에서는 2.5m 쯤 된다. 그리고 玄室바닥에서 封土頂部까지의 高는 6.5m가 된다. 封土는 砂質粘土를 물에 익여서 단단하게 다진 것이며 慶州地區의 古墳과 同一하다.

玄　室

玄室은 東西 2.5m, 南北 3.7m, 高 3.1m의 南北으로 若干 길은 矩形이며 큼직큼직한 自然石 또는 割石으로 쌓은 四壁은 南·北壁은 直立이지만 長壁인 東, 西, 兩壁은 上部에서 점점 內傾하고 길게 좁아진 天井部는 自然石 四枚로 덮고 있다. 天井石 下面에는 灰칠 위에 그려진 蓮文이 一部 남아 있다. 壁面의 灰칠은 거의 脫落하였으나 南壁의 上部에 一部 彩色자국이 남아 있다. 玄室은 于先 그 四周 幅 27~8cm, 깊이 22cm 정도의 도랑(排水溝)을 파돌리고 거기에는 자갈돌을 玄室바닥 높이까지 채우고 그 上面 房全體에 걸쳐 엷은 石板을 一列 깔은 다음 그 위에 灰를 섞은 흙을 2~3cm 덮고 있다. 이것이 玄室의 바닥이 된다.

그 바닥 위에 다시 割石을 一列로 깔고 고운 흙칠한 棺臺가 만들어지는데 棺臺의 높이는 9m 가량이고 크기는 西棺臺가 南北 2.8m, 東西 1.3m, 東棺臺가 南北 2.8m, 東西 0.86m, 두 臺사이 間隔은 30cm로 되어 있다. 西棺臺는 西壁에서 約 10cm 가량 떨어져 있고 또 그 位置로 보아 이 玄室의 主棺臺라고 생각되며 東棺臺는 크기도 작고 또 東壁에 꼭 붙어 있어 어딘지 군색해 보이나 두 棺臺의 築造先後 關係는 構造上으로는 看別할 수 없다.

壁에는 全面으로 灰칠을 하였는데 그 大部分이 떨어져 나갔으며 一部에는 黃褐色粘土에 3~4cm의 볏집을 섞어 바르고 그 위에 엷게 白灰를 칠한 것과 그대로 흙만을 바른 등등의 二次的 補修한 部分이 있다. 한편 盜掘孔에 나타난 壁斷面을 보면 그 石材들이 長邊 50~60cm, 短邊 80cm, 厚 30cm 內外임을 알 수 있었다. 그리고 灰칠 속에는 굴껍질이 섞여 있어 이 灰가 구운 굴껍질 粉임을 알 수 있다.

羨　道

羨門은 玄室南壁에 東偏하여 있으며 高·幅모두 60cm로서 方形을 이루며 위에는 큰 自然石楣石을 올려 놓고 있다. 羨道의 바닥은 羨門에서 1.5m 頃까지는 平面으로 가다가 그 位置에서 10cm 假量 一段 높아졌고 그대로 約 1m 더나가 雜石과 粘土로 閉塞된 入口部에

到達한다. 羨道의 壁의 築造와 灰칠은 玄室과 같고 天井은 7枚의 長大石을 가로 덮고 그 下面에도 엷게 灰칠을 한 다음 紅, 綠, 褐色으로 總 11개의 蓮文과 雲文을 그리고 있다. 한편 羨道의 東壁下部(棺臺끝에서 南으로 1.4m 位置)에서는 두께 2.5cm의 元 灰칠面 表面에 紅, 黑色으로 唐草文의 一部같은 그림이 남아있어 여기도 元來 壁畵가 있었음을 알수 있었다. 그런데 이 羨道東壁部에서는 元來 灰칠 위에 다시 黃褐色 粘土(벼집섞음)를 바르고 灰칠을 한 第1次 補修와 다시 그 위에 黑褐色精土를 씌운 第2次 補修가 層位를 이루며 남아 있는 部分이 있어 玄室壁面에서의 觀察과 符合하고 있다.

이러한 2次에 걸친 壁面의 修理는 이 무덤이 完成된 뒤 적어도 두번 開門되고 사람이 出入했다는 事實을 말하고 있는데 棺臺는 두개 뿐으로서 追加葬은 一回밖에 없었던 것으로 되기 때문에 좀 理解하기 困難하다. 그래서 故人의 生存時에 이미 壽陵으로서 이 무덤이 만들어졌다가 第1回 葬禮時에 벌써 壁面脫落된 部分이 있어 그 部分에는 진흙으로 때우고 灰칠을 하였고 다시 第2回 葬禮時에 또 脫落된 部分이 있어 그것을 黑褐色 흙으로 메운 것이라고 解釋하던가 그렇지 않으면 古墳이 第1回 被葬人埋葬時에 만들어진 것이지만 工事가 疎忽해서 이미 第1回 葬禮時에 脫落된 部分이 생겨 다시 灰칠을 하고 壁畵도 追彩하였고 그後 第2回 葬禮時에 2次 補修를 한 것이라고 보아야 할 것이다. 그러나 그 어느쪽이 眞相이었는지는 알 수 없다.

天井蓮花文

玄室天井에도 蓮文이 있으나 아주 희미해서 細部를 알 수 없고 南壁上部에도 무슨 草文같은 色彩가 있으나 脫落이 甚해서 原形을 알아 볼 길이 없다. 따라서 여기서는 羨道天井下面에 있는 蓮文만에 關해서 細部를 살펴 보겠다. 이 蓮花文은 羨門(玄室入口)部에서 시작해 左右로 두개, 다음에는 한개, 다음에 또 두개, 그런 順序로 해서 두개짜리가 넷 한개짜리가 셋, 都合 11개가 남아 있다. 이 꽃들은 크기에 若干씩의 差異는 있으나 典型的인 一例는 最大徑 26cm며 花房을 中心으로 八瓣의 大小二種의 蓮花를 겹친 複合蓮花이며 花瓣과 花瓣사이에는 꽃술이 하나씩 配置된다. 花房은 綠色, 花瓣은 周緣部에는 粉紅色暈色으로 칠했고 中心部는 白色으로 남기고 있는데 花房中心으로 褐色의 꽃줄을 한 줄기씩 그리고 있다. 잎은 綠色.

以上과 같은 二重蓮文 周邊에는 褐, 綠, 紅色으로 波文같은 雲文을 그리고 있다.

高句麗·百濟 石室墳과의 比較

南向하는 羨道달린 石室墳은 高句麗·百濟·新羅가 모두 가지고 있으나 新羅에서는 數도 적고 統一期에 들어서부터 어느 程度 廣用되는 것이기 때문에 異質的인 存在였다고 할 수 있으며 이러한 石室墳은 高句麗에서 시작해 百濟로 들어간 麗濟式墓制라고 할 수 있을 것이다. 더구나 羨道가 南壁中央에 달리지 않고 한쪽에 偏在하는 경우에 高句麗에서는 殆半이 高靈式으로 東壁에 接해서 열려 있으며 例를 들면 高山里五號墳, 晩達山麓古墳群(14基中 13基)등이 있다(昭和二年度, 十二年度 古蹟調査報告). 百濟古墳에 있어서는 宋山里 1, 2, 5號, 羅州潘南面 興德里 石室墳, 驪州上里 1, 2號 古墳등과 같이 偏東羨門이다(考古學雜誌 24卷 9號 所收 輕部慈恩論文). 그러나 慶州忠孝里의 統一期石室墳에 있어서는 中央에 연린 5, 7號 2基를 除外하고는 1, 2, 3, 4, 6, 8, 9, 10 各號가 모두 偏西羨門이며 麗濟式과는 反對로 되고 있는 것이다(昭和七年度 古蹟調査報告第二册).

이렇게 볼 때 우리 高靈古蹟이 于先 平面構造에서 麗濟式을 따르고 있는 것은 分明하다.

다음 立體的으로 볼때 高靈古墳의 터넬式 玄室 即 南北壁은 垂直인데 東西의 두 長壁에 內傾하여 아—취式 斷面을 形成하고 있는 것은 高句麗 古墳에서는 볼 수 없고 도리어 百濟 古墳 即 有名한 公州宋山里의 壁畵博墳에서 보는 바이며 이것은 元來는 華南地方의 六朝墓制에서 배워온 것이다. 그러나 우리 高靈古墳이 直接 華南으로부터 그것을 배워 왔다고는 볼 수 없으며 百濟를 通해서 그 아이디어를 얻었다고 보는 것이 가장 妥當하다.

한편 여기 壁畵가 元來 무엇을 主題로 하고 있었는지는 알 길이 없으나 남아 있는 部分으로 보면 獨立된 蓮花文들이며 그것이 側面이 아니고 平面俯瞰圖인 點과 또 花瓣輪廓을 朱色暈彩하고 있는 筆法 등은 어딘지 扶餘陵山里 壁畵古墳의 그것과 相通하며 銳利한 輪廓으로 되어 있는 高句麗의 蓮花와는 距離가 있다.

以上과 같은 點에서 또 地理的인 關係를 考慮해도 石室墳, 壁畵 그 自體는 그 根源이 高句麗가 되겠지만 여기 高靈古墳이 直接 範本으로 하고 그에게 直接 作用한 것은 百濟의 古墳이었다고 믿어지는 것이다. 結局 百濟의 墓制는 高靈地區까지 오면서 洛東江을 넘지 못하였던 것이다.

이 壁畵墳은 비록 一基라고는 하나 그것의 伽耶地區內의 存在는 伽耶의 政治的 文化的 性格에 關해서 하나의 새로운 面을 보여 주었다고 하겠으며 여러가지 意味에서 重要하다

고 하겠다.

出土遺物

墓室內는 모두 盜去·攪亂되었기 때문에 遺物도 거의 아무것 없고 또 그 位置도 問題가 안되나 人骨·土器片·못類가 採集되었고 또 封土周邊에서 盜去中 破損되었다고 생각되는 土器片이 二, 三片있었다. 그리고 이 古墳의 盜掘者가 逮捕된 結果 過去 安東이니 玄風出土니 하여 오던 金銅鞍金具一式이 이 古墳에서 나온 것임을 알게 되었다.

土 器 片

破片이지만 灰白色無文土器로서 口唇을 가진 盆形器였다고 생각되며 口徑 16cm, 두께 8미리다.

封土外部에서 採集된 土器片은 一列(四개 ?)의 方形透孔을 가진 坩脚破片(底徑 16cm), 같은 坩脚片 1, 그리고 格文의 흔적이 있는 破片 1, 그리고 脚附坩 또는 杯破片 1이 있다.

못 類

青銅못 4개

半球形鈑頭를 가진 긴 못이며 釘身은 斷面 方形이고 기리는 各各 5.2, 5.0, 4.5, 4.0cm 이다.

鐵못 三개

亦是 角形못인데 머리가 그리 크지 않고 꺽쇠같은 感을 준다. 前者와 같이 모두 棺에 使用된 것이라 하겠다. 기리는 各各 6.4, 6.2, 5.8cm 이며 表面에는 木理가 남아 있다.

金銅鞍金具 二

이것은 秦弘燮敎授의 紹介文(「金銅鞍裝金具의 新例」 考古美術 4卷 7號, 1963年 7月)에 依하면 元來 慶北 安東郡 一直面 古墳에서 1961年 11月에 盜掘된 것이라 하며 現物은 慶北大學校 博物館에 있었으나 慶北大學校 博物館刊行의 仁同古墳報告 附錄(1966年)에는

玄風古墳이라고 되어 있다. 그러나 이것은 이번 壁畵古墳發見後 逮捕된 盜掘人의 陳述에 依하여 이 高靈古墳에서 나온 것임이 判明되었으며 現品은 現在 國立博物館으로 移藏되었다.

이 鞍金具는 前輪(幅 40.5cm, 高 25cm), 後輪(幅 56.5cm, 高 30cm)이며 모두 三國時代에 盛行한 怪雲文이 透刻되어 있다. 그리고 여기 附着되었던 木片을 慶北大學에서 東京의 理化學研究所에 보내어 炭素年代測定結果 1780±130年前으로 나왔다.

人　骨

室內各處에 흩어진 人骨片인데 꼭 어느 棺臺라고 定할 수 없다.

頭蓋骨片, 右下顎骨片, 頸骨, 胸骨, 腰骨, 上膊骨, 肩胛骨, 肋骨 등이 있으며 成人男子의 遺骨이라고 보인다.

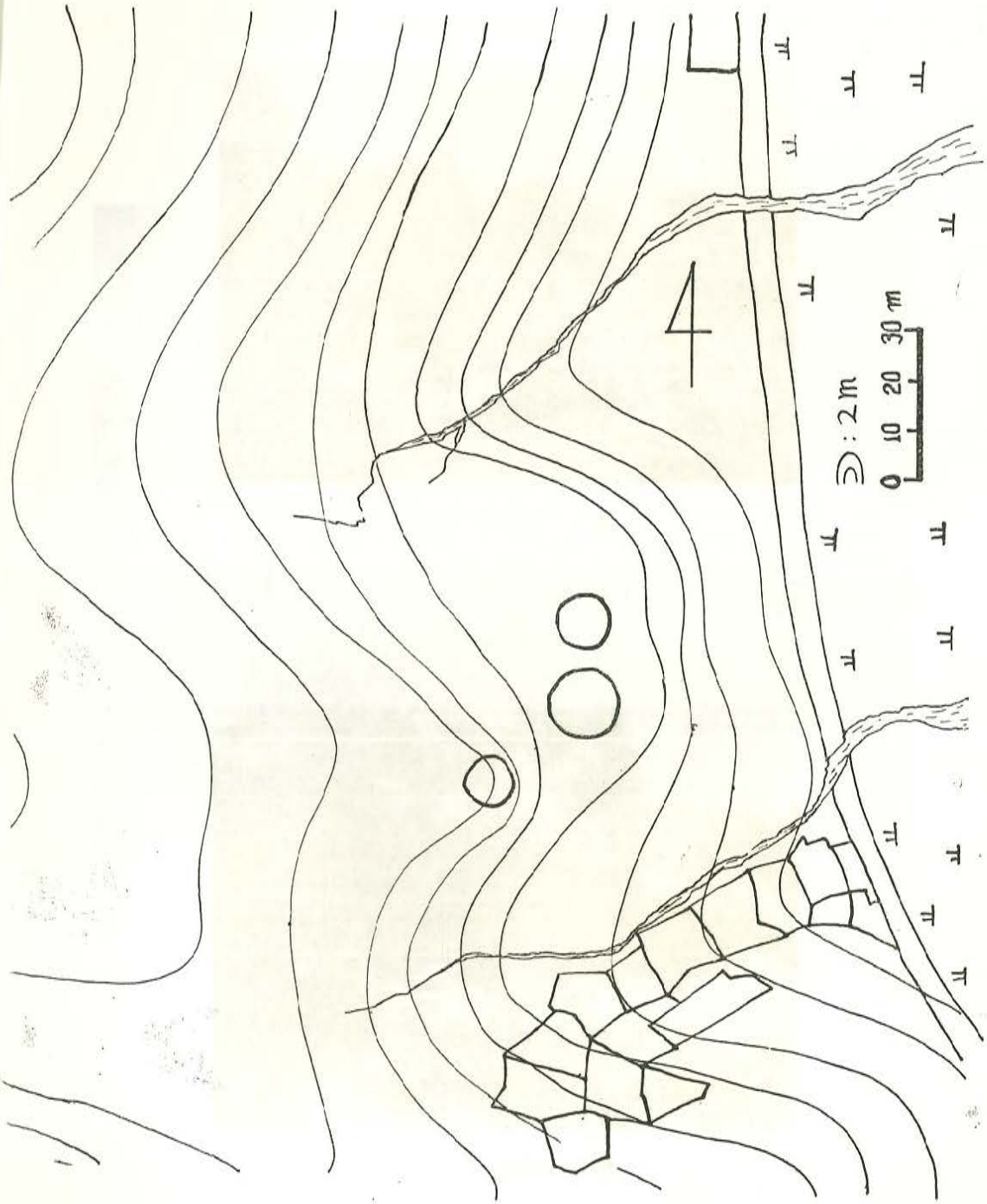


圖 1. 古墳附近地形圖

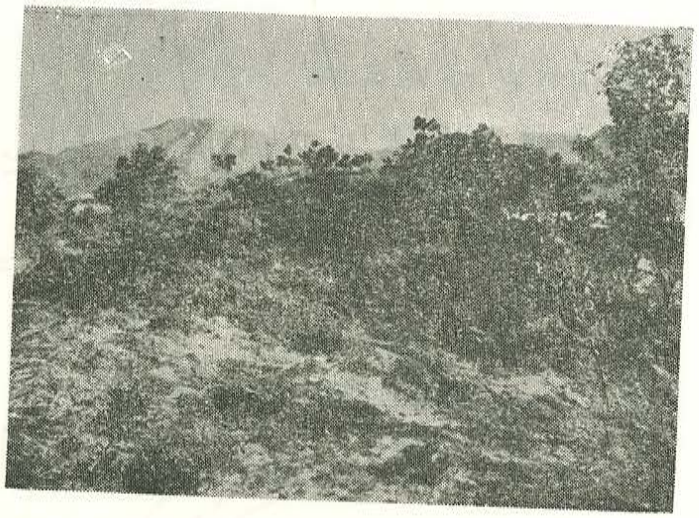


圖 2. 封土原狀（北）

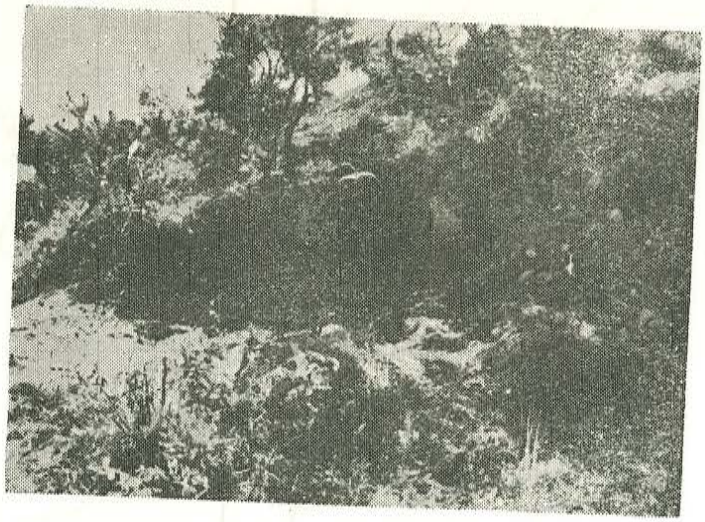


圖 3. 盜掘坑（北）

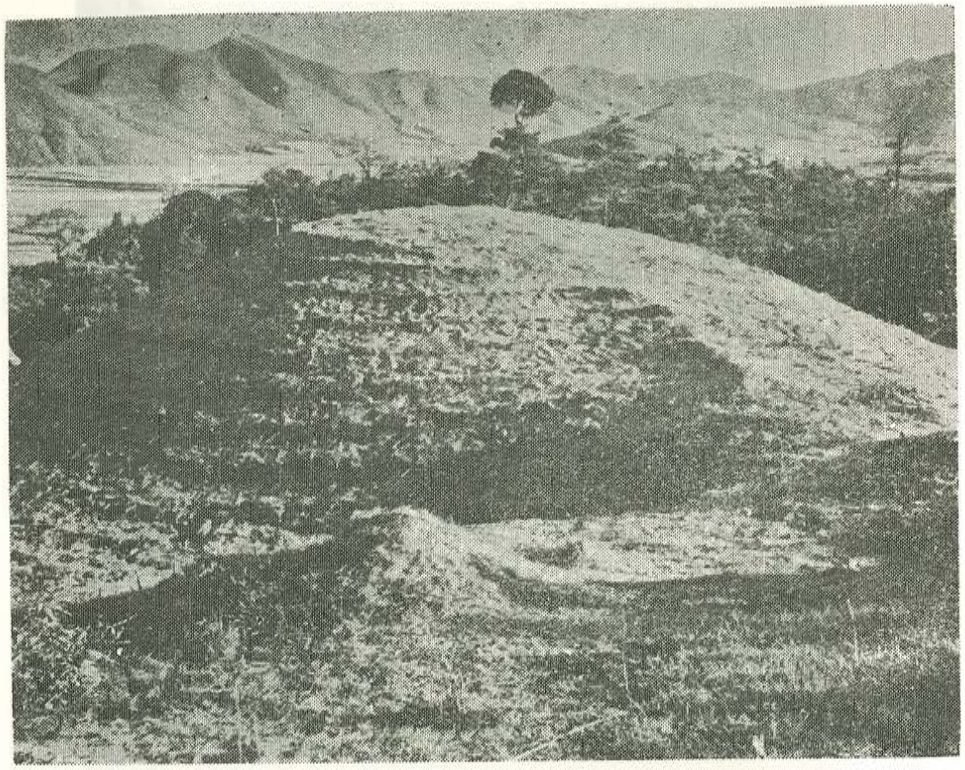


圖 4. 封土修理後（北）

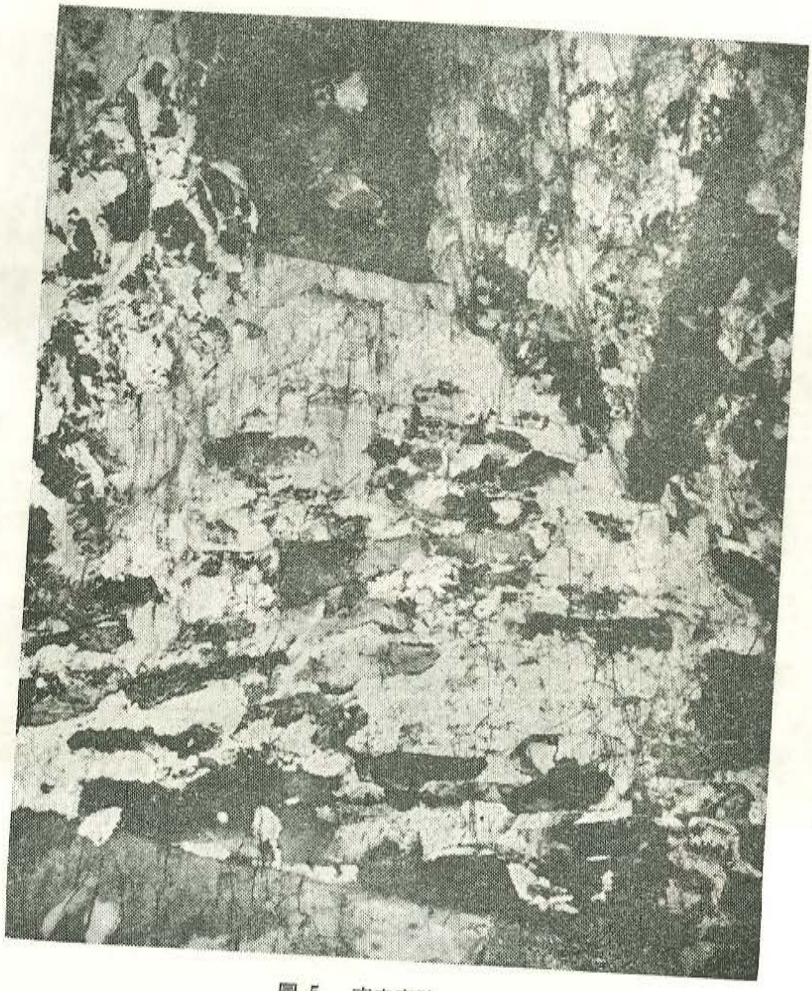


圖 5. 玄室南壁

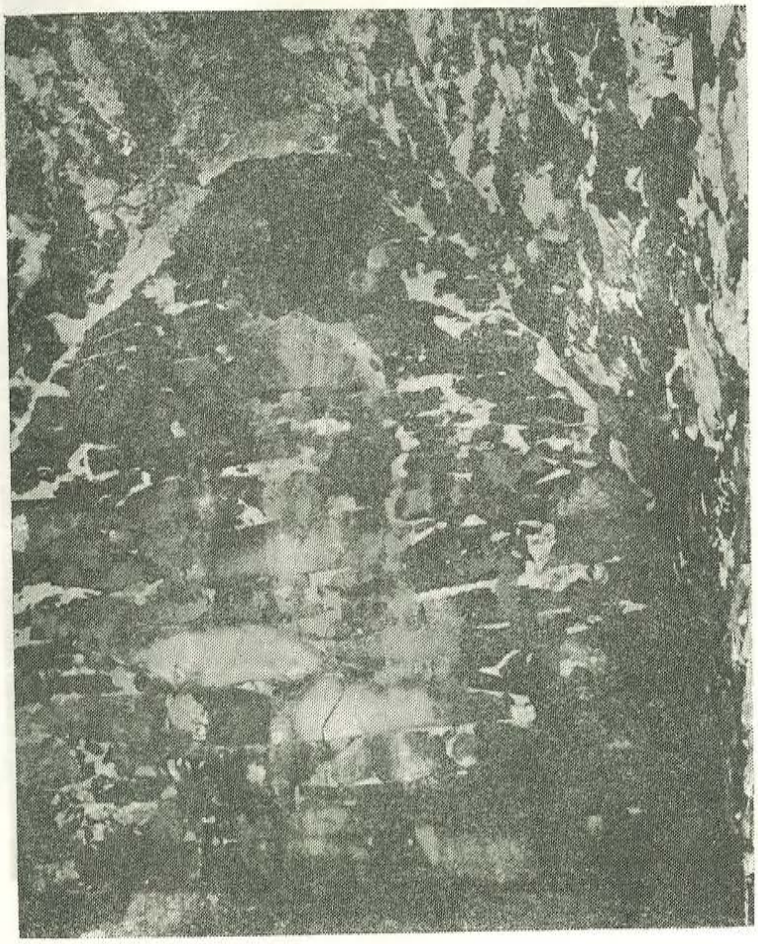


圖 6. 玄室北壁(盜掘口)

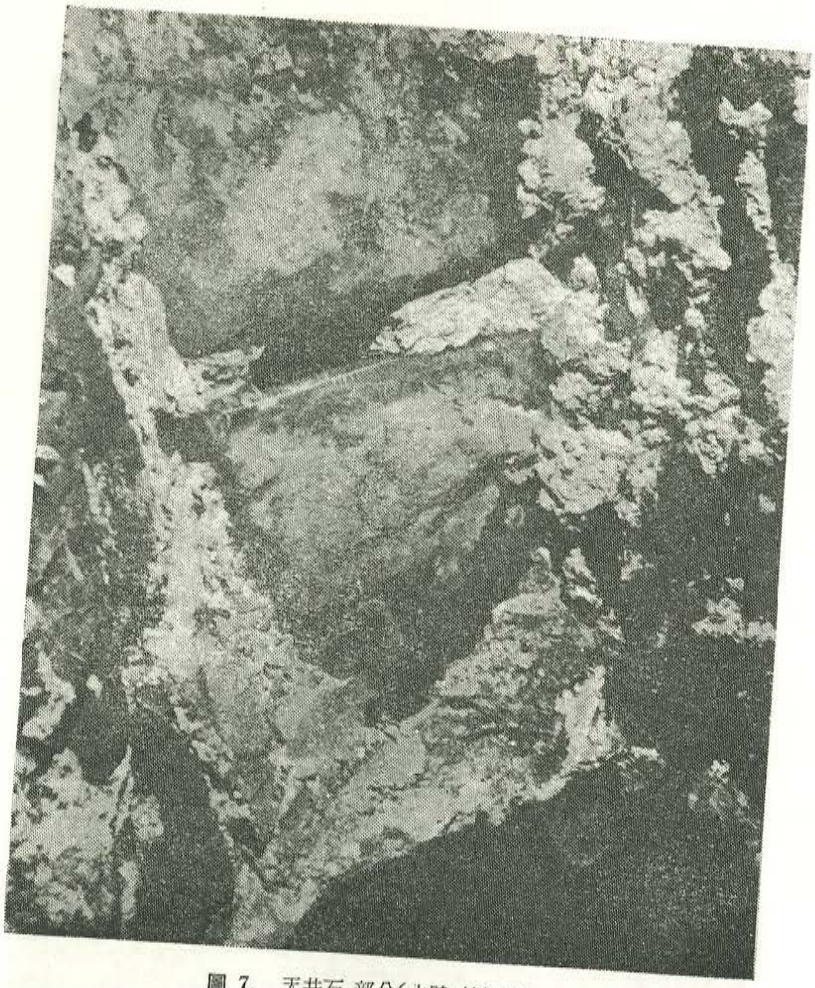


圖 7. 天井石 部分(北壁 接觸部)
(蓮花文이 희미하게 보임)

圖 8, 玄室에서 羨道를 본것(木扉는 修理後 架設)

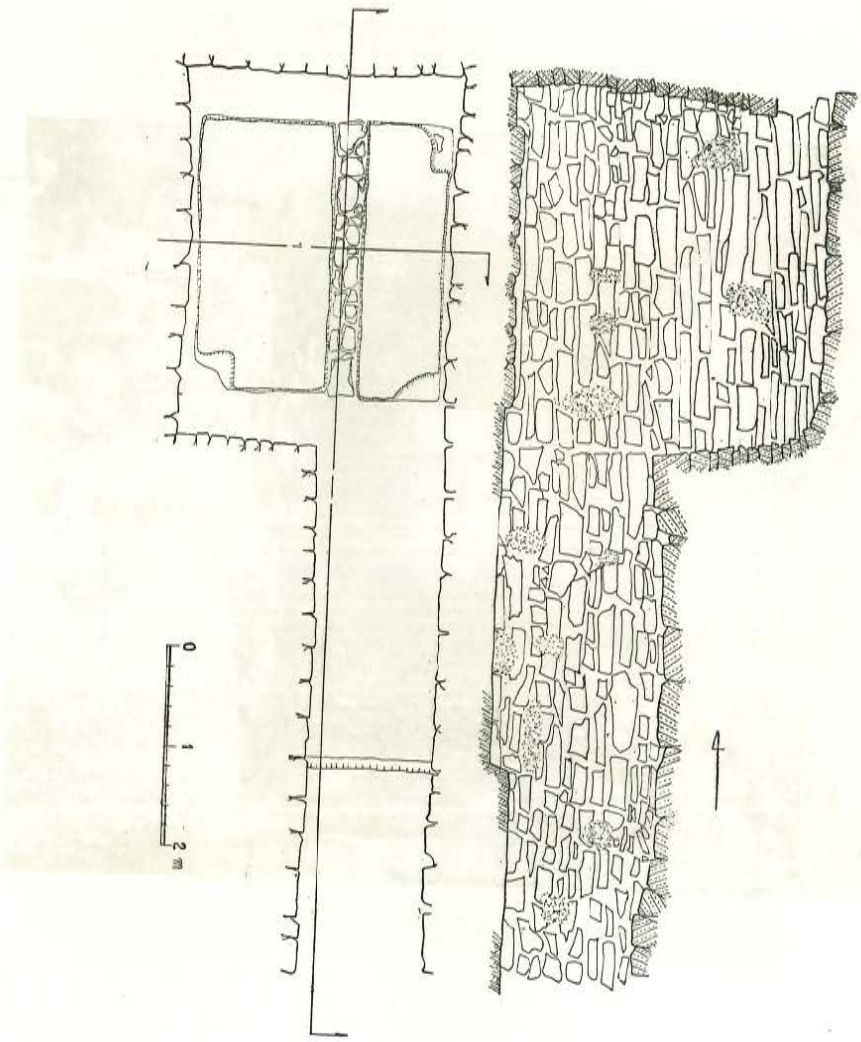


圖 9. 玄室平面 및 縱斷圖(南北)

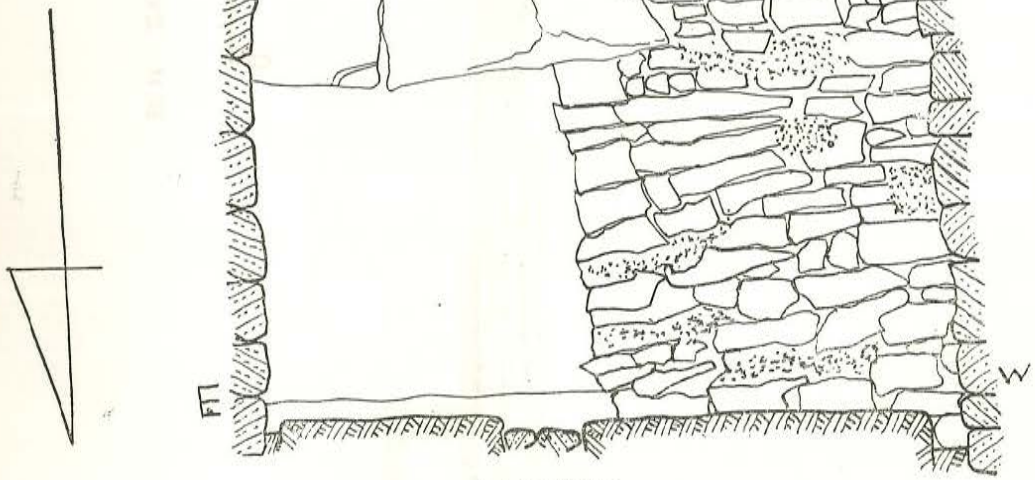


圖 10. 玄室南壁實測壁

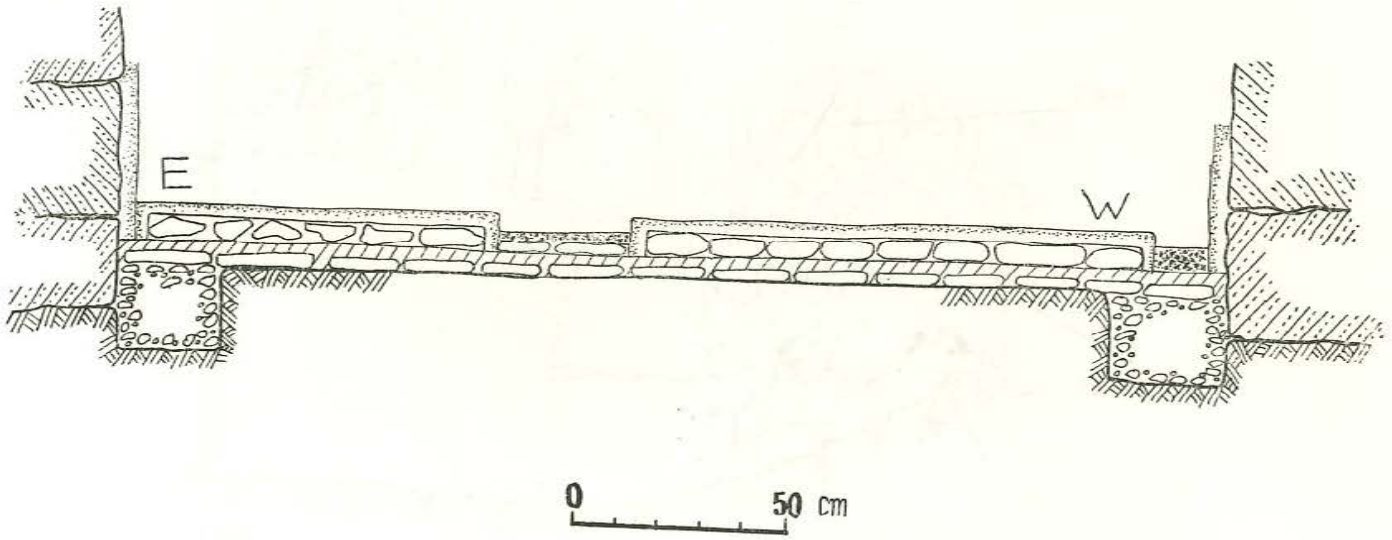


圖 11. 玄室바닥東西斷面復原圖

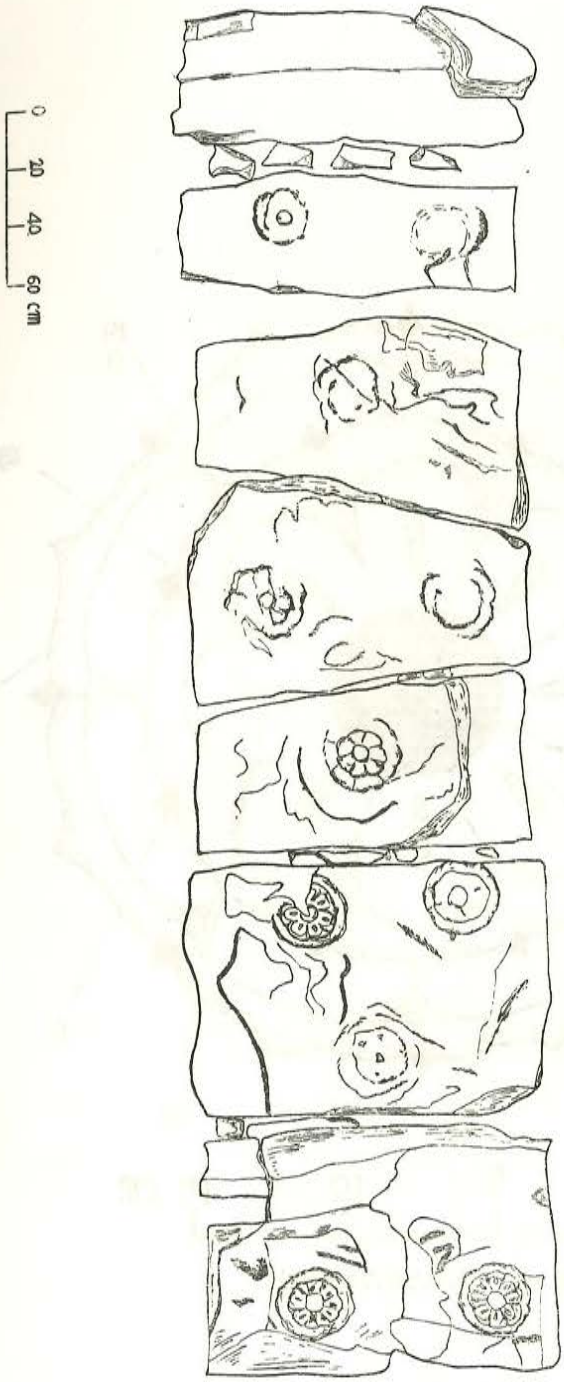


圖 12. 義道天井壁畵實測圖

圖 11. 玄室바닥東西斷面復原圖

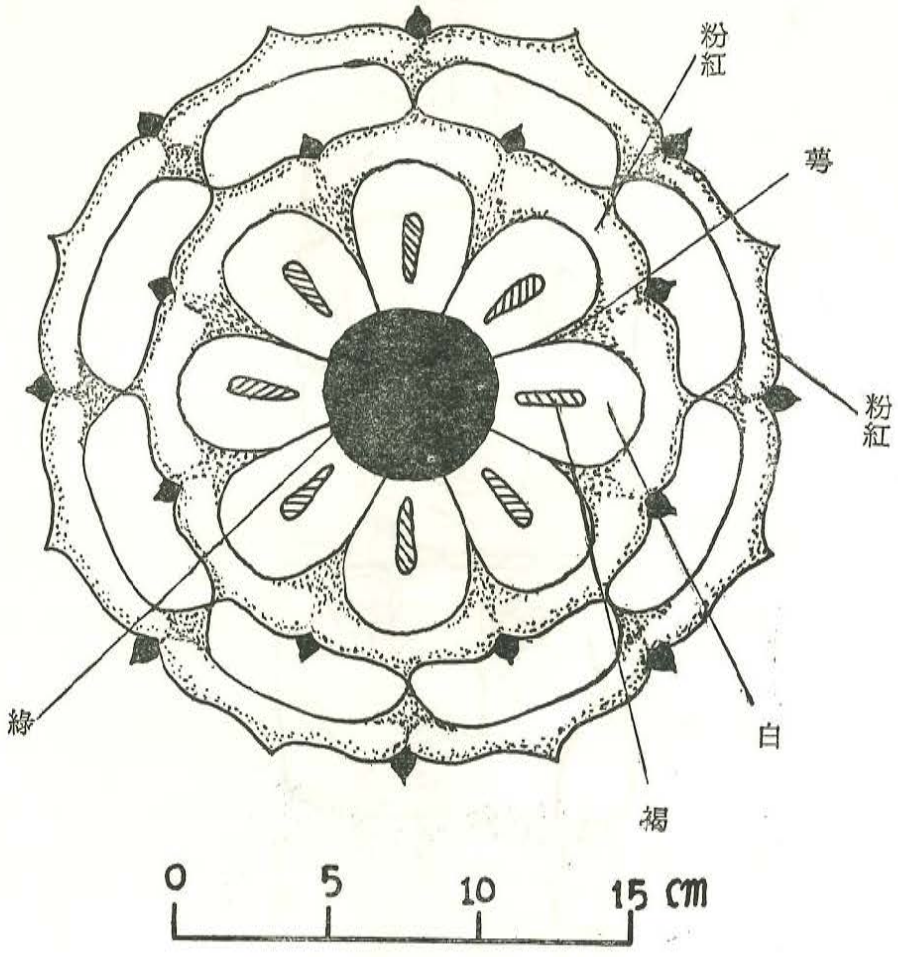
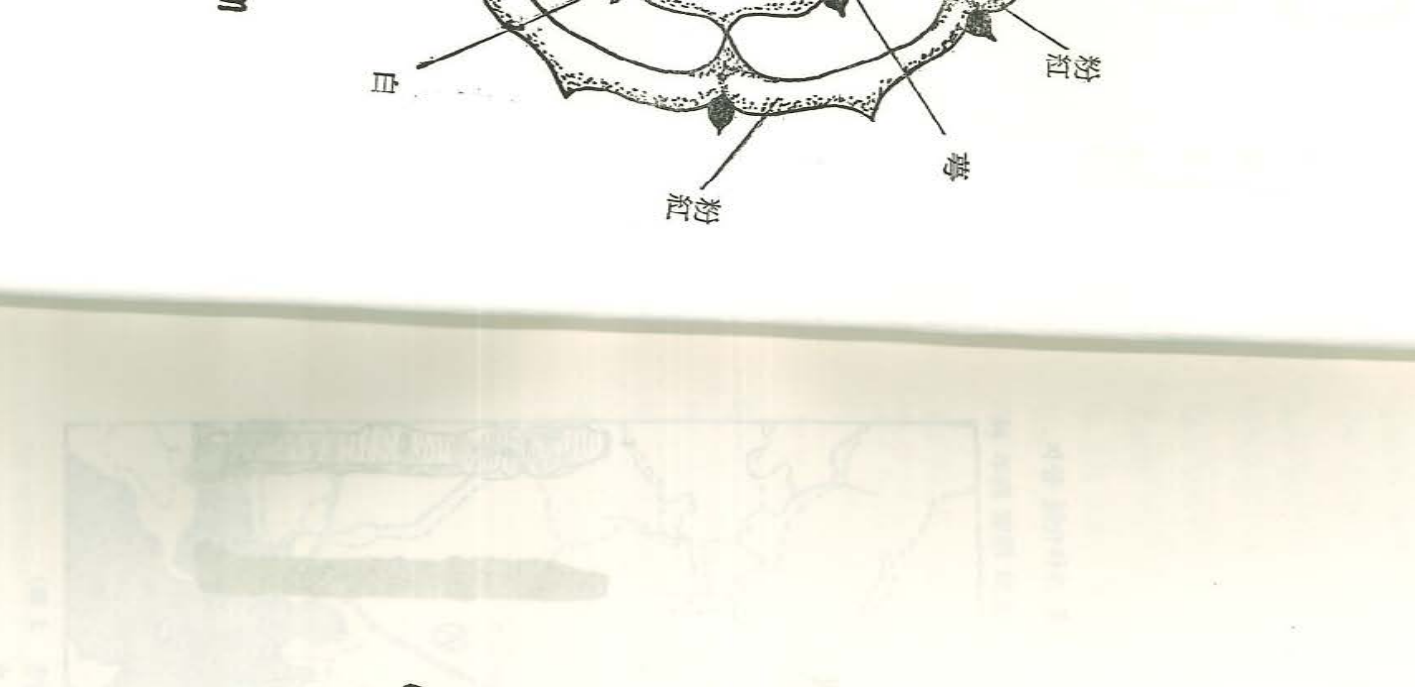


圖 13. 淺道天井蓮花文復原圖



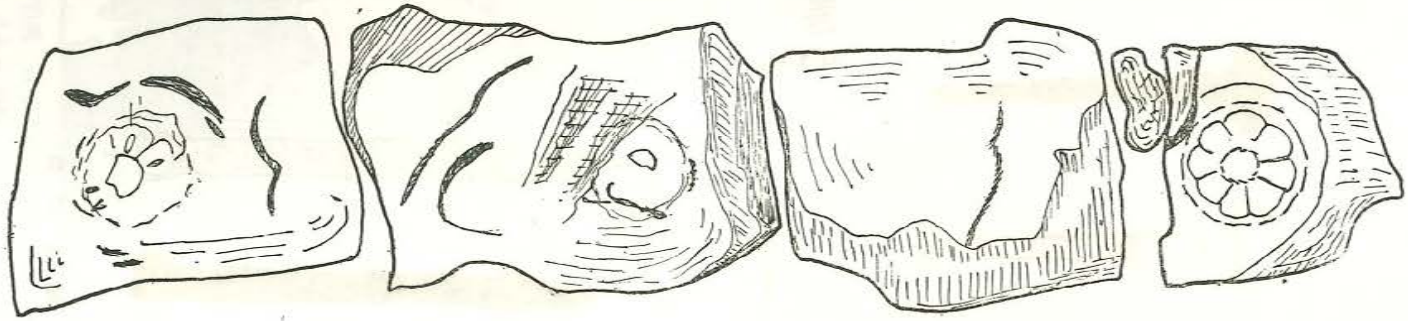


圖 14. 玄室天井壁畵配置圖

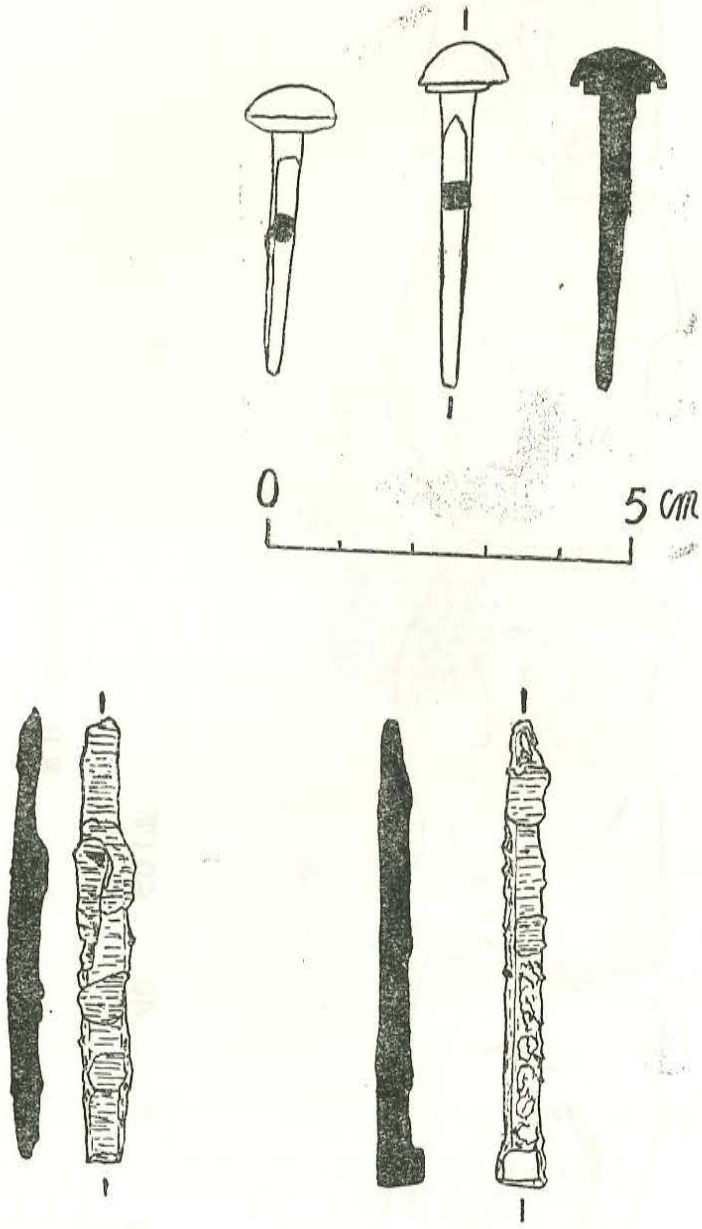


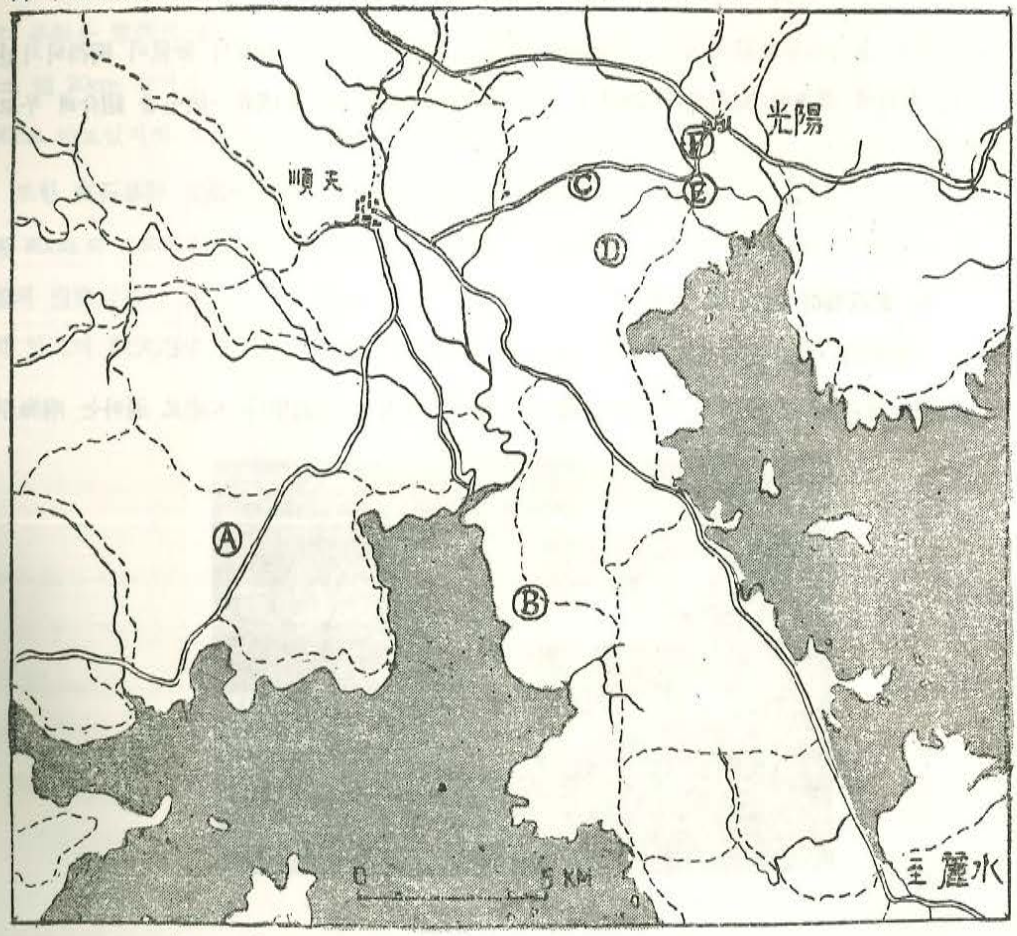
圖 15. 釘 類

順天地區 支石墓群

任 孝 宰★

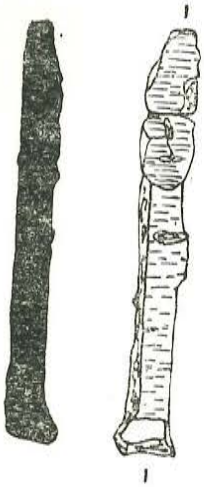
(1)

지금 紹介하는 先史遺蹟遺物은 지난 4月 20日부터 約1週日間 서울大學校 考古人類學科 年例 定期 踏査의 一環으로 主로 全南 地方의 古刹을 探訪後 남은 餘暇를 利用하여 順



(圖 1. Ⓐ石峴 Ⓑ 弄珠里 Ⓒ 福星里 Ⓓ 福星里平化 (E) 回岩里 Ⓕ 回岩里

★ 서울大 助敎



天市를 起點으로 10km 以內에 該當되는 昇州郡·光陽郡 一部 海岸地域을 放射狀의 地上踏査에서(圖 1 參照) 얻은 部分的인 結果이다,

일찌기 이 地域은 三韓의 故土로 그 海岸은 典型的인 Rias式 海岸地帶를 形成하여 半島모양의 陸地部가 多島海 멀리까지 突出하였기도 하지만 海水가 內陸 깊숙히까지 流入하였던 곳곳은 現在 防潮堤堰에 依하여 田畓으로 轉用되고 있으며 이와 接續되는 平地나 山脈의 鞍部에서는 相當數의 巨石物 및 이와 關聯된 遺物이 發見되었다. 이들은 모두 南韓古代社會의 初期金屬期文化를 解明, 例示하는 重要 資料들로서 今般의 좁은 範圍의 踏査地域에서 相當數의 支石墓가 發見되었고 또 最近에 無土器文化의 打製石器片의 發見이 報告된일도 있고[1] 해서 크게 注目을 끄는 地域이기도 하다.

앞으로 全南海岸地域에 對한 廣範圍한 調査로 더많은 새로운 事實의 發見이 期待되지만 于先 今般에 調査한 支石墓群 數例와 立石 그리고 磨製石劍 未成品一例만을 紹介해 두고져 하는 바이다.

(2)

A. 支石墓群 數例 및 立石

石峴의 立石 支石墓群

石峴部落은 全南 昇州郡 別良面에 屬하고 順天市에서는 筏橋里나 木浦로 通하는 南海岸

(圖 2)

(1) L.L. SAMPLE & A.MOHR. 「Progressive Report on the Chronological Research in the Republic of Korea」 Arctic Anthropology Vol II, # 1 1964. U.S.A.

諸地域을 連結하는 大路를 따라 西南方 約 7km 地點에 있으며 支石墓群은 路邊의 石峴部落과 雲川里를 가로막고 있는 獨立된 호리병모양의 山間을 넘어가는, 稜線部 편평지역에 都合 7基의 大小支石墓가 2~5m 間隔을 둔채 20×20 평방미—터內에 群集하고 있다(圖 2). 部落人들은 옛부터 兩部落 境界面에 巨石이 있어 「돌고개」라고 불러왔다고 하는데 現在는 이곳에 두채의 집이 파수병인양 兩部落을 지키고 있을뿐 人家와는 떨어져 있으며 小路擴張工事로 一部 支石墓 上石의 原位置가 옮기어져 長軸의 方向은 一定하지 않으나 最大形의 경우 最大長 4m 50cm 最大幅 1m 30cm 두께 40cm의 長楕圓形 上石을 갖고, 最大長 1m 30cm 最大幅 90cm 두께 25cm인 上石은 最小形에 屬한다. 이들은 모두 地形의 傾斜關係로 支石墓의 上石 以下의 構造가 完全히 묻히어져 있으나 家屋垈地(金善女氏宅) 工事中 長軸을 東西로 둔 板石 支石墓의 內部 一部가 露出된 最小形 支石墓의 一例에서 高 10 cm 幅 20cm 크기의 塊石 2個로 上石을 받치고 있는 것이 뚜렷하였다. 이 두 塊石間을 約 50cm 파보았지만 고운 土砂만이 나올 뿐 遺物은 全無이었다.

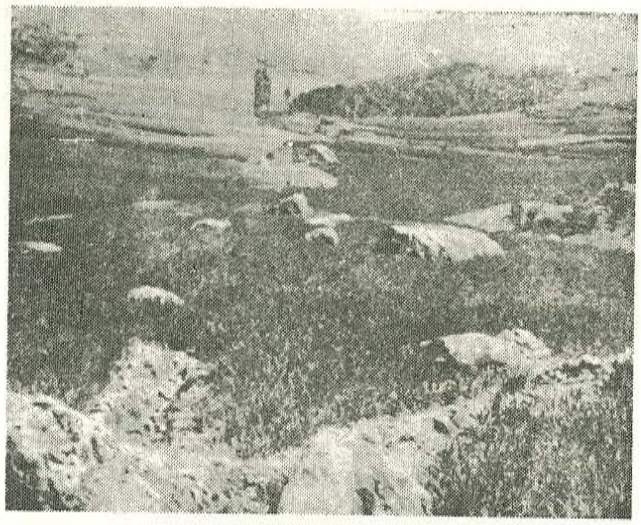
또한 支石墓群 北端에는 圖 3에서 보는 巨石을 (高 2m 50cm 幅 1m 60cm) 높이 45cm 幅 80cm의 4角形石 2個로 고이고 있는 外形上 滋味있는 立石이 서있으며 周圍에는 數個의 自然巨石이 있다. 이와 같이 支石墓와 立石이 同一場所에 隣接되어 있는 경우는 흔히 있으며 順天市의 立石도 그 周圍에는 많은 支石墓가 있었다고 한다(2).

(圖 3)

(2) 鳥居 龍藏「朝鮮 全羅南道順天立石里に 於ける メンヒルに 就て」人類學雜誌 37卷 4號 pp. 358~326

弄珠里 支石墓群

順天市 南方 約 10km 地點에 있는 弄珠里部落은 順天市에서 每日 5回 往復하는 順天~下沙間의 뻐—스로 約 50分 所要되는 곳으로 行政區域上 昇州郡 海龍面 弄珠里에 屬한다. 支石墓群은 終點인 下沙里와 弄珠里를 分岐하는 고갯마루에 都合 5基가 一部는 破壞되어 土砂에 묻힌채 東西를 長軸으로 順天灣을 向하고 있다(圖 4). 이중 完全한 支石墓의 上石은 長楕圓形으로 貧弱한 塊石을 눌르고 있는데, 이들 支石墓群을 中心으로 한 金正坤



(圖 4)

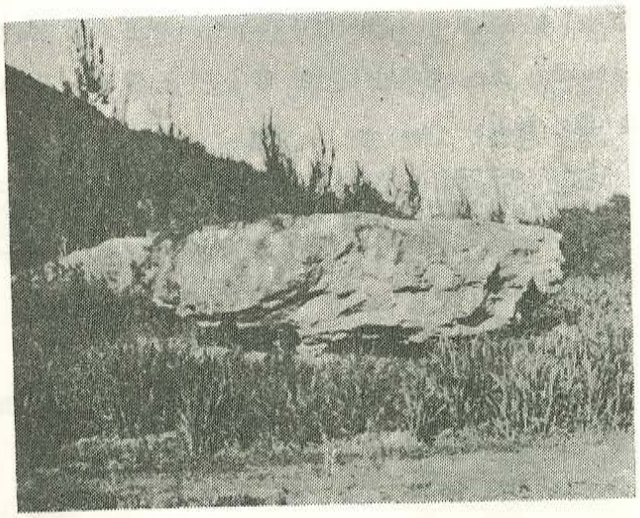
氏 밀밭 周圍에는 立體形 自然 巨石이 多數 있다.

福星里 支石墓群

順天市에서 光陽邑까지는 約 8km로서 그 中間 地點에는 南北으로 계속되는 山脈이 가로 막혀 있다. 따라서 順天市에서 이 地點까지는 계속 傾斜路를 올라가야만 되는데 그 頂上部 附近 昇州郡과 順天市 境界面 野山에 三基의 支石墓가 있다. 이곳은 昇州郡 海龍面 福星里 上飛部落에 屬하며 밭主人 金錠春氏에 依하면 옛부터 이곳에 巨石이 있어 部落人은 「바우백이」라고 불러왔다고 한다. 長軸을 南北으로 두고 重疊된 板石이 長楕圓形의 上石(最大長 3m 20cm 最大幅 1m 80cm 두께 70cm)으로 重壓된 一基는(圖 5) 道路邊에서 約 10m 程度떨어져 있기에 車窓에서도 쉽게 볼 수 있다.

支石墓가 位置한 地帶는 南高北低인 關係로 上石의 南側은 150cm 두께의 板石만으로, 北側은 40cm 크기의 塊石하나로 높게 받치어져 上石의 平行을 維持하고 있다.

이 上石下를 試掘하여 보았으나 數많은 板石破片만이 出土되었을 뿐 다른 遺物은 없었다.



(圖 5)

福星里 平化 支石墓 一基

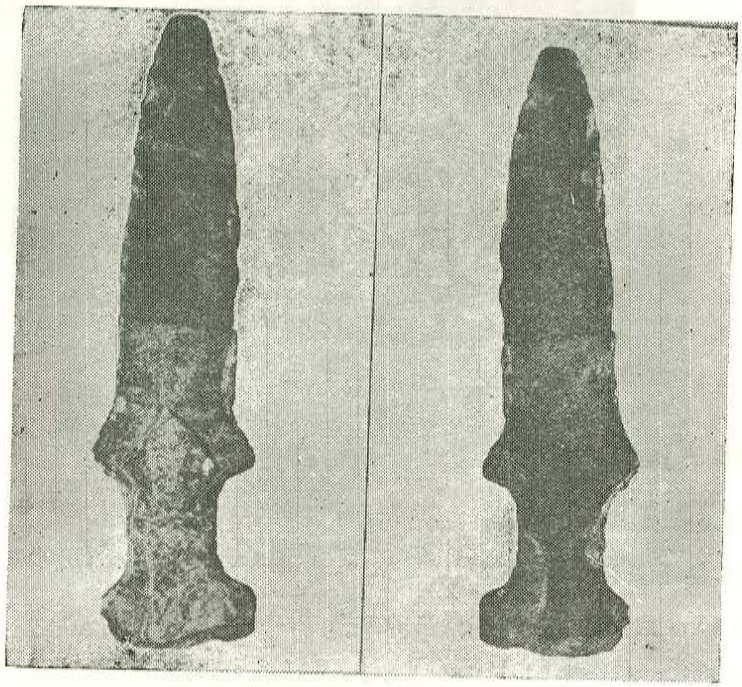
上述한 福星里 支石墓 群集地에서 約 1500m 南向하면 平化驛으로 通하는 山길 小路가 今年 正月에 開通된 慶全線 鐵路와 交叉되는데 이곳에 이르는 고갯길에 長軸을 東西로 한 最大長 2m 80cm 最大幅 1m 80cm 두께 50cm의 閃綠岩製 長楕圓形 上石이 半切된채 申福守氏 所有 밀밭에 있다. 現在 上石의 北側만을 除外한 三隅에 50 cm 크기의 塊石으로 받쳐 있으나 本來는 北側에도 같은 크기의 塊石으로 받치어져 있었다고 생각되며 이것은 後日 洞里人들이 石材의 利用을 目的으로 破壞流失된 것으로 보인다. 따라서 支石墓의 上石이 半切된 것도 이로 因한 自體의 重壓에 못이긴 結果가 아닌가 생각된다.

現在 支石墓의 上石은 周圍의 밭보다 若干 돋우어진 곳에 놓여 있으나 이는 開墾時부터 모아 놓은 돌과 흙이 쌓인 것으로 생각된다.

B. 磨製石劍 未成品 一例

順天市서 光陽邑까지는 東方 8km 程度의 短距離로서 光陽邑을 中心으로 東西兩側에는 南流하는 乃川이 바다로 流入되고 있으며 若干의 平地가 계속되고 있다. 그런데 順天서 光陽으로 가자면 道路를 따라 光陽初入의 西川을 건너야 하는데 바로 西川橋를 건느기 前에 光陽郡 光陽邑 回岩 部落이 있다.

여기 紹介하는 磨製石劍 未成品은 連續된 西山 山脈이 直接 西川과 連結되는 傾斜面에 位置한 回岩部落앞을 지나는 水路開拓工事中 地下 約 1m 깊이에서 同種의 未成品과 같이 朴基鉉氏에 依하여 約 3年前에 採集되었다고 한다. 그間 同氏 家內 保管中인 두개중 하나는 紛失되었고 여기 보는 한개만이 남아 있던 것을 筆者가 入手하여 現在 서울大學校 博物館에 保管中이다(圖 6).

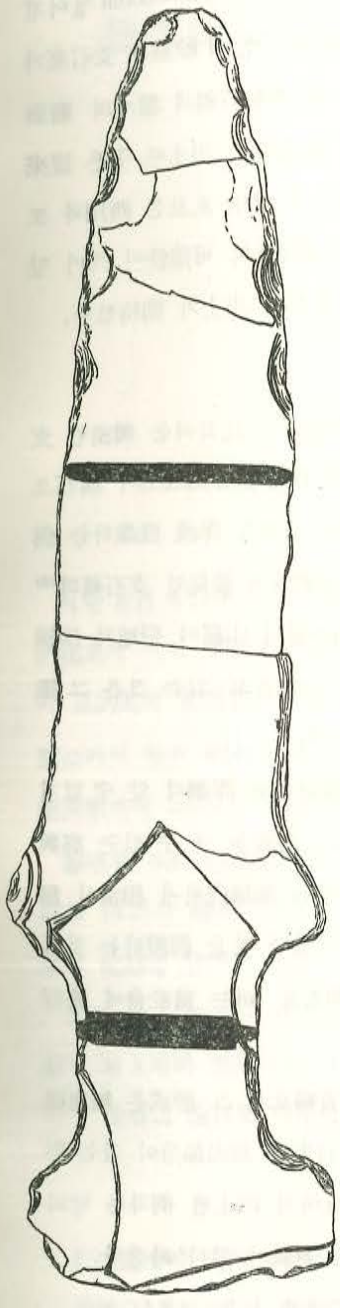


(圖 6)

이 石劍은 全長이 3.0cm 이고 身幅이 5.5cm 의 粘板岩製이며 全體的으로 얇고 幅이 넓은 편인데 刃部 및 鐔部·把頭部가 明確히 刻出되어 磨製石劍의 全體的인 輪廓만을 조심스럽게 打整한 것이다. 그런데 이 輪廓만으로도 南韓에서 集中的으로 出土되는 有光博士의 所謂 BⅡ形에[3] 近似한 것을 알 수 있다. 다만 未成品이기 때문에 鎬가 없고 劍把部에 刻出部分이 있는 點에 特徵이 있다.

于先 劍部에 있어서 劍鋒周緣에 조심스러운 打整을 加하고 鐔部에 이르는 보드러운 曲線을 維持하고 있다. 그리고 前面과 後面은 扁平하여 그 斷面은 扁六角形에 가깝다(圖 7). 鐔部에 가까운 刃部에 若干의 磨研 痕跡이 보이는 것으로 보아 石劍·輪廓의 成形後 磨研

(3) 有光教一 朝鮮磨製石劍の 研究(京都大學文學部 考古學叢書 第3册 1962)



(4) 有光敎一上揭書

過程으로 들어가다가 잘못하여 半切, 抛棄된 것이 長期間 地下에 묻히어서 各各 다른 風化變化度의 結果 身部片은 黑灰色을, 劍把部는 軟灰色을 露呈하게 된 것이라고 믿어진다. 그런데 前記한 바와 같이 未成品의 特徵의 하나가 鏑가 없는 點인데 元來 鏑의 生成은 打整의 過程이 끝나고 磨硏過程에서 이루어 진다면 그 作業에 들어가기 前에 부러져 버린 것이다. 그러나 原石의 두께가 0.4cm라는 너무 얇은 것이기 때문에 當初부터 鏑가 없는 曲面形式의 劍을 만들려고 하였는지도 알 수 없다. 이 點은 有光博士의 BⅡ形의 基本型이 次次 變化退行하면서 그 斷面이 얇고 扁平化하는 一傾向(4)과 關連을 가진 것인지도 모르겠다.

柄部에는 一段柄式의 石劍製作을 위한 明確한 雙曲線이 打缺되어있고 突出된 鐔部의 길이는 4.7cm 把頭部는 4.3cm로서 全體的인 比率은 좋은 편이다. 그런데 全長에 $\frac{1}{3}$에 該當되는 劍把部는 두께 0.6cm로서 劍身部보다 若干 두꺼우며 大體的인 輪廓은 되어 있으나 完成品으로 되려면 部分的인 打整과 힘든 磨硏作業을 해야 할 것이다.

全體的으로 보아 身部의 兩刃과 鐔部 및 把頭部 그리고 劍把部에 나타난 明確한 雙曲線은 標識的인 有光博士의 BⅡ式 group에 屬하지만 前記하다시피 劍身은 鏑의 生成은 없었을 것이다.

유감스럽게도 伴出遺物에 關하여는 採集者에 依한 同形의 未成品이 地下 1m程度의 깊이 에서 같이 나왔다는 事實뿐이며 當時의 狀態에 對한 것을 알 수가 없다. 現地 踏査의 結果 現場은 이미 cement에 依한 水路工事로 以上의 調査는 不可能하였다.

그런데 이곳 附近에는 前記한 支石墓數例以外에도 바로

回岩部落內 鐵路邊 車勝順氏 宅옆에 一基의 支石墓가 있고 西川橋 건너 500~600m 떨어진 金滋均氏 所有밭에도 一基의 支石墓가 있다. 더우기 金氏談에 依하면 十餘基의 支石墓가 群集되었었으나 石材使用을 目的으로 爆破當時 巨石下에서 一개 磨製石劍과 數개의 磨製石鏃이 發見되었다고 한다. 前述한 諸事實로 미루어 보아 이 未成品이 出土된 곳은 從來의 磨製石劍出土例가 主로 埋葬址인 것과는 달리 西山을 背景으로 앞에 흐르는 西川과 또한 南海를 生活舞臺로 한 支石墓社會人의 住居址 乃而는 石器製作址의 可能性이 크며 앞으로 철저한 調査에서 많은 磨製石劍 製作過程을 밝혀 주는 資料의 出土가 期待된다.

(5)

以上과 같이 短時日內 좁은 範圍에 걸친 調査이었지만 踏査範圍에 比하여는 稠密한 支石墓의 分布例를 發見하였고 이들의 外形은 長楕圓形의 上石을 貧弱한 2個以上의 塊石으로 받치고 있는 것과 單只 20~30cm 두께의 板石만으로 構築한 石室을 保護 標識하는 例等이 支配的이었고 이들은 外形上 高興郡이나[5] 이에 隣接된 島嶼에서 發見된 支石墓의[6] 諸形式과도 共通된 것을 알 수 있다. 또한 이들의 所在地가 例外없이 山脈이 平地와 接續되어 海岸이 보이는 山脈間의 鞍部 또는 交通路上의 分岐點에 位置하고 있는 것은 그 築造에 있어서 地理的 背景이 強하게 考慮되었음을 推測할 수 있다.

簡單한 地上調査이었으므로 支石墓의 內部 構造 및 內容에 關하여는 詳細히 알 수 없지만 支石墓下 長方形 石室에서 銅劍이 出土되어 部分的이나마 그 內容을 알 수 있는 高興郡 豈原面 雲垈里 支石墓群[7]과는 가깝게 있고 今般에 調査한 좁은 地域內에서 相當히 稠密한 分布例 및 立石의 共存等은 太陽巨石文化가 相當히 무르익었던 것을 例證하는 것이며 特히 磨製石劍 未成品의 出土도 磨製石劍을 支石墓의 副葬用으로 하는 當社會에 流行된 風俗의 副產物이라고 할 수 있겠다.

特히 이 未成品의 出土는 磨製石劍의 製作過程을 밝혀 주는 資料로서 그 形式은 無血溝一段柄式에 屬하며 그 特徵은 劍身部에 鎬가 없으며 劍把部에 特異한 刻出部分이 있는 點이다. 또한 出土場所도 從來의 磨製石劍의 大部分이 主로 埋葬址에서 出土된 例와는 달리 住居址나 石劍製作場所의 可能性이 있는 곳에서 發見된 點에 큰 意義가 있다 하겠다.

(5) 梅原末治 朝鮮古文化 綜鑑 第1卷
藤田亮策 p 87. 및 最近의 國立博物館의 調査結果
(6) 最近 서울大學校에서 實施한 南海 島嶼의 考古學調査中 高興郡에 屬한 外羅老島 內羅老島에서 發見된 支石墓群
(7) 梅原 末治
藤田亮策 上揭書

蘇爺島 所在 新發見의 貝塚과 其 出土 遺物

崔 夢 龍★

順 序

Ⅰ. 序 言
Ⅱ. 位置 及 遺蹟現況
Ⅲ. 遺 物
A. 土 器
B. 石 器
Ⅳ. 結 言

Ⅰ. 序 言

지난 6月 6日부터 9日까지 三泊四日에 걸쳐 考古人類學科 遺蹟踏査를 櫛文土器貝塚의 所在로서 이미 學界에 잘 알려진 京畿道 富川郡 德積面 蘇爺島(德積群島)[1]로 定하게 되어 目的地에 到着하던 첫날 筆者는 本島 蘇爺里 큰마을 入口 釜上(가마위)의 小路에 面해 露出되어 있는 貝塚을 發見하여 거기서 櫛文土器片 여러 點과 精巧한 打製石器를 數點 表面採取하여 그곳이 打製石器를 隨伴하는 櫛文土器 遺蹟임을 確認하였다.

筆者는 本科 踏査團員들이 蘇爺里에 滯在하던 이틀동안 前後 四次에 걸쳐 表面調査한 結果 18點의 櫛文土器片과 6點의 石器를 拾得할 수 있어 遺物을 通해 새로이 發見된 貝塚의 性格을 究明해 보고져 한다.

또한 南쪽 海邊 김진재氏 所有 밭결, 수풀에 둘러싸여 잘 보이지 않으나 分布範圍가 相當히 넓으리라 推測되는 貝塚(圖 1의 ×3)을 發見하였으나 時間의 制約上 仔細한 調査를 하지 못하고 後日로 미루어 두는 바이다.

Ⅱ. 位置 及 遺蹟現況

仁川港에서 西南方 約6時間 배를 타면 蘇爺里 津邊에 이른다.

津邊(나룻터)에서 東南向해서 險峻한 山길을 約 15分 걸어 가면 基洞이란 마을이 나타

(1) 金載元·尹武炳:「韓國西海島嶼」(1957年刊) pp. 11-17

★ 考古人類學科 四年

나는데 이곳에서 本貝塚이 所在하고 있는 蘇爺里 큰마을 入口에 이르는 길은 海岸線을 따라 가파른 山腹을 가로질러 깎은 지름길과 標高 156m 國祀峰 산등성이를 타고 내려오는 두가지가 있는데, 貝塚은 基洞에서 前者의 海岸線을 따라 3·4年前 小路를 좀더 擴張해서 생긴 길로 들어서야 쉽게 찾아 볼 수 있는 것이다.(圖 1 및 圖 2 參照)

圖 1. 貝塚分布圖(×4 一年 全京秀 學友가 發見한 貝塚)

이 貝塚은 圖 2에서 보는 바와같이 金賢起氏 宅 西側 約 8m 떨어진 現在 三基의 墳墓가 造營되어 있는 釜上의 아래측 金氏 先山의 山腹 即, 前記 基洞에 이르는 小路上의 斷崖部에 東西長 約 13m에 걸쳐 露出되어 있으며 또한 一部가 小路의 南側 海邊에 이르는 산등성이(現在 田畓으로 使用)에서도, 또는 金氏 先山 東北方 4~5m 떨어진 곳에서도 約 40cm 가량의 貝殼層을 形成하고 있어 3~4年前 小路擴張以前에는 分布範圍가 相當히 넓었으리라 쉽게 斟酌할 수 있는 것이다.(圖 3 및 寫眞 1 參照)

現在 小路面에 露出되어 있는 斷面을 보면 雜草가 茂盛한 地表아래 20~27cm에 이르는 明褐色 表土層, 그다음 露出部分이 햇볕에 잘 쐬여서 그런지 遺物을 包含하고 있는 混土貝殼層은 비교적 下部에 비해 黑褐色調를 보여주면서도 밝은 明褐色을 띄우고 있다.

小路의 地表와 面하고 있는 腐蝕層은 陰地의 탓인지 또는 貝殼의 腐蝕程度가 심해서인지

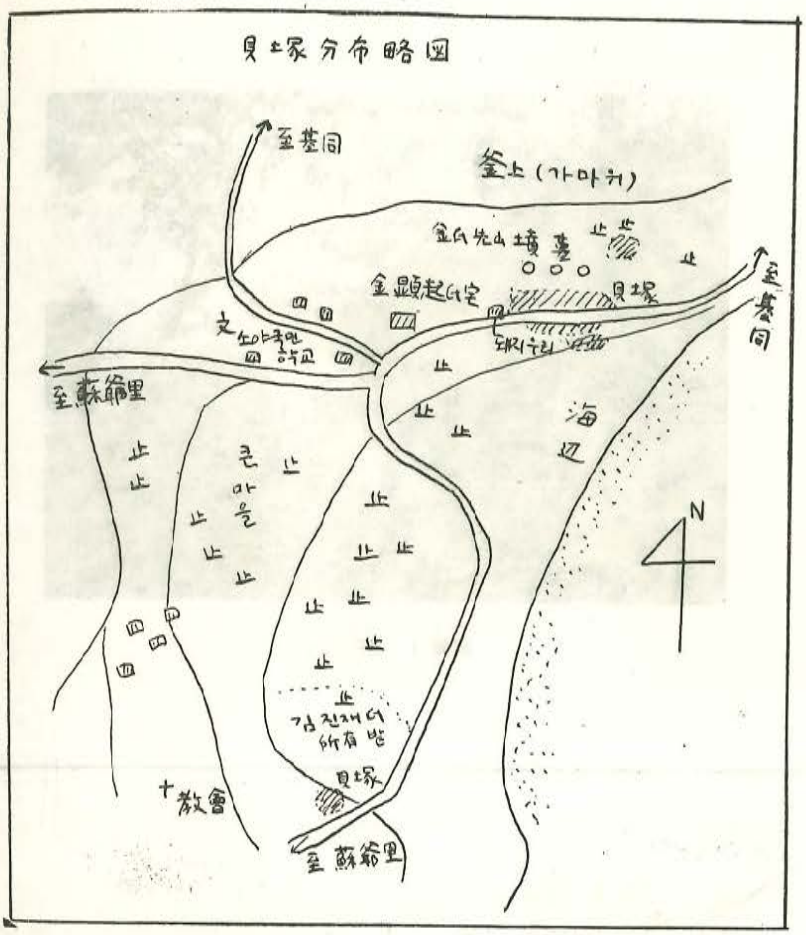


圖 2 貝塚分布略圖

짙은 銀灰色을 보여주며 다른 面에서는 上部와 같이 黑褐色을 보여주고 있는 곳도 있다. (圖 4 斷面圖 及 寫眞 2 參照)

III. 遺　物

A. 土　器

採集된 土器片은 18點으로서 모두 吸水性이 強한 異質的인 櫛文土器片들이며 또한 全長 3.5cm를 넘지 못하는 小破片들이라 元來의 器形을 復元하기에는 困難한 形便이나. 그런대로 희미하나 文樣을 보여주는 것이 5點이나 있어 여기에 紹介해둘 價値가 있다고 생각된다.

寫眞 1 遺蹟現況

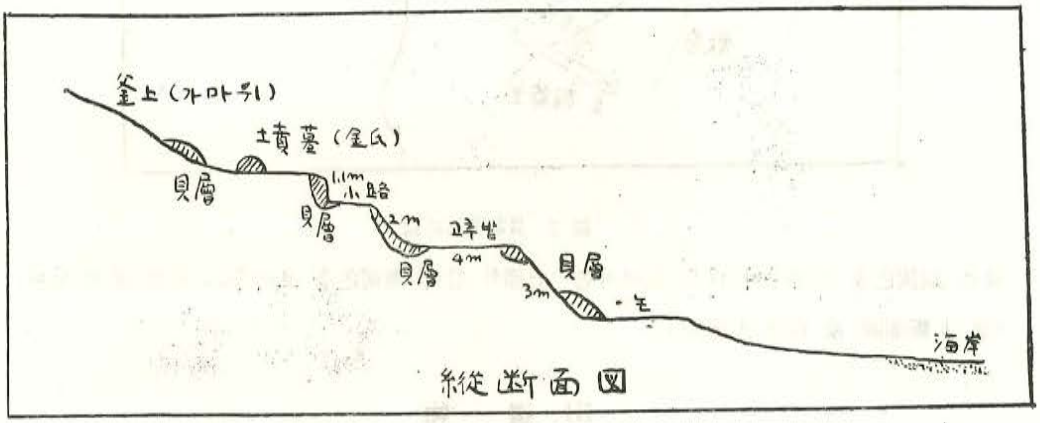


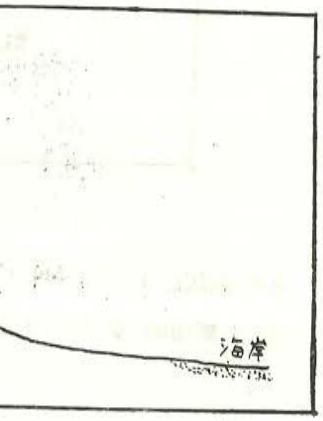
圖 3 縱斷面圖

1. 寫眞 3의 1

內外壁 모두 같은 色調인 黑褐色을 띠우고 있으며 胎土의 質은 雲母片으로 因하여 반짝거리고 있고 간혹 굵은 砂粒이 보이긴 하지만 비교적 精選되었다고 말할 수 있다.

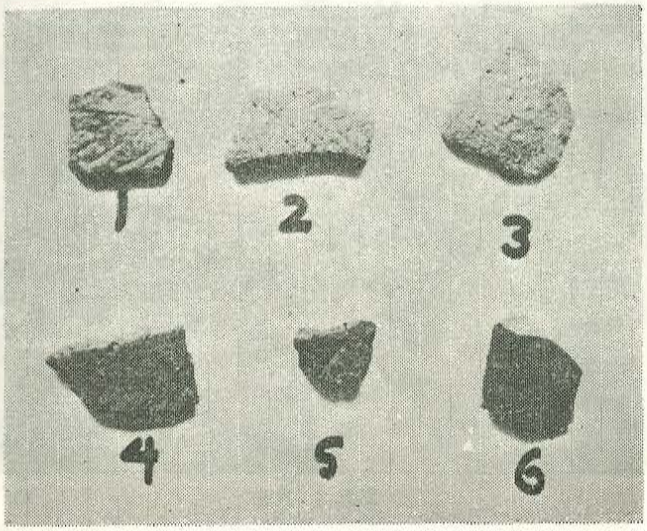
器壁의 두께는 0.6cm 이다.

文樣은 現在 三條의 列點文 아래에 斜線文이 보이고 있어 岩寺里 遺蹟의 土器片과 共通



은 雲母片으로 因하여 반짝
다고 말할 수 있다.

寺里 遺蹟의 土器片과 共通



寫眞 2 土器片

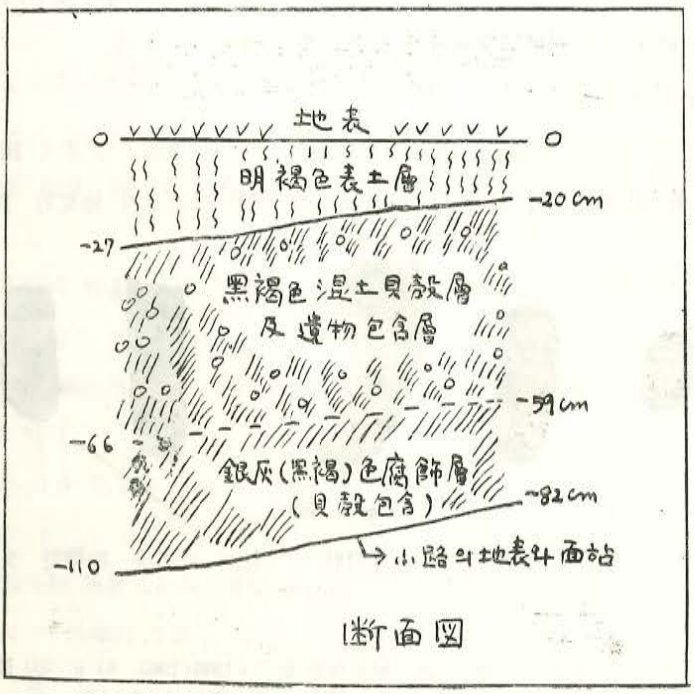
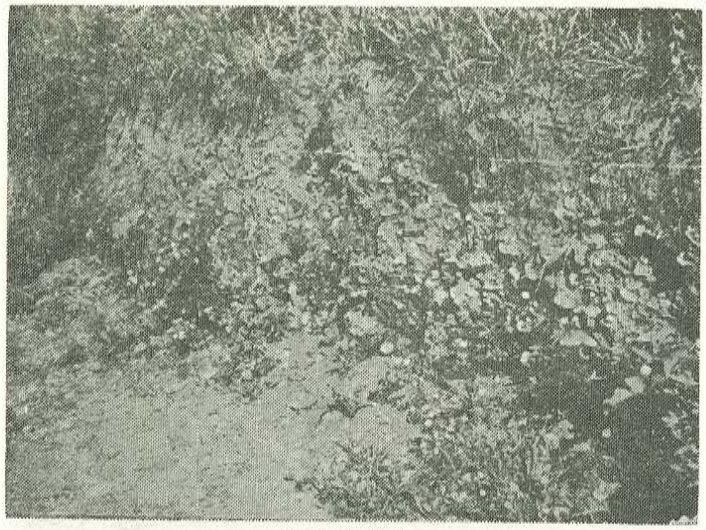


圖 4 斷面圖



寫眞 3 貝層

點을 보여준다고 하겠다(2).

2. 寫眞 3의 2

外壁은 紅褐色, 內壁은 不完全 燃燒의 탓인지 더 엷은 明褐色을 보여주고 있으며 이것도 亦是 굵은 砂粒과 內外壁器表面에서 雲母片을 確認할 수 있다.

器壁의 두께는 0.7cm이다.

外壁의 表面에 나타난 文樣은 五條의 斜線文이 꺽여져 菱形의 折半에 該當하는데 一見 漢沙里 出土 櫛文土器片中에 鳥骨·齒牙나 貝殼類 같은 것으로서 施文한 斜交集線文(3)으

圖 5 器壁

로 생각되며 또한 「西海島嶼」에서 言及된 羽狀의 文樣이 이것을 指稱한 것이 아닌가 推測된다(4).

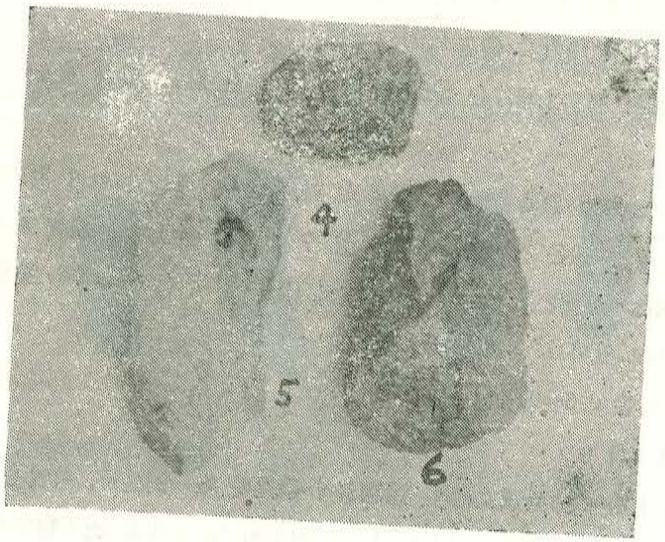
(2) 金元龍 : "岩寺里 遺蹟의 土器·石器" 歷史學報 第17·18輯(1962. 6) p. 360 圖 4의 下
(3) 金元龍 : "廣州漢沙里 櫛文土器 遺蹟" 歷史學報 14輯(1961. 4) p. 139
(4) 金載元·尹武炳 : 前揭書(註 1) p. 17

1. 石質은 石英으로 되어 있으며 斷面은 菱形을 보이고 刃은 兩側에 蛤刃을 달았으며 一見 刃器로 使用되었으리라 推測되나 用途不明이다. 이런 類의 五角形 石器는 "領津里·加屯里 櫛文土器遺蹟"에서 報告된바 있다[5].

2. 搔削器 形石斧

石英質로서 一面은 自然石理에 依해 扁平한 面을 이루고 있는 反面, 다른 面은 周緣에

寫眞 4 石器(1)



寫眞 5 石器(2)

(5) 任孝宰·鄭永和："領津里·加屯里櫛文土器遺蹟"(1965年 서울大 卒業論文)

打整을 加해 刃部를 銳利하게 가다듬어 自然石理의 背面와 함께 蛤刃의 形態를 이루었다. 이와 같은 例는 天安市 鳳龍洞 山上 無文土器 遺蹟에서 發見된바 있다(6). 그러나 당장 文化上 그곳과 무슨 關聯이 지어진다는 것은 아니며 앞으로의 더많은 資料를 必要로 하는 것이라 하겠다.

全長 8cm.

3. 大形石斧： 自然石을 그대로 利用하여 만든 石器로서 把手部分에는 손에 쥐기 좋도록 修正을 加하고 또 刃部에는 使用의 痕迹으로 보이는 損傷이 나있다.

石質은 硅長岩(Felsite)이며 全長 12.5cm 이다.

4. 剝片刃器

母石으로 떼어낸 小形剝片으로서 一面은 自然石質을 그대로 두고 刃部의 周緣을 따라 精巧하게 修整을 加한 小形剝片刃器이다.

石質은 硅長岩이여 全長 6cm.

5. 石斧： 石英質로서 一見 自然石을 그대로 利用하여 打碎器로 使用한 것 같으며 打擊面에 修整을 加한 痕迹을 보이고 있다. (圖 6)

6. 前記 5 項과 같은 大形石斧形刃器로서 未完成製品이나 石器로서 使用이 된 듯하다.

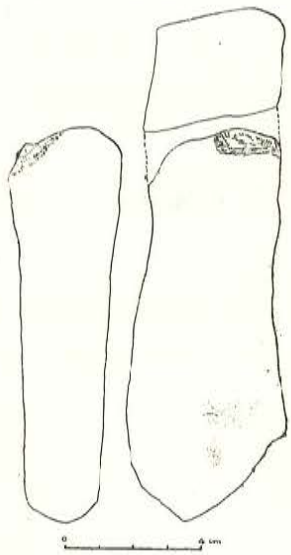


圖 6

(6) 金元龍："天安市 鳳龍洞山上 無文土器遺蹟" 震檀學報 第 29・30 合併號 1967年, p. 37

IV. 結　言

以上 土器·石器의 說明을 綜合要約하여 이 貝塚의 性格을 究明해 보면, 于先 櫛文土器片을 보면 비록 文樣을 갖고 있는 것이 5點밖에는 안되지만 그 中에는 列點文 아래에 斜線文이 보이는 岩寺里 櫛文土器遺蹟 出土 土器片과 또한 渼沙里 出土 斜交集線文과 共通의 土器片들이 出土되고 있어 性格을 究明하는데 좋은 資料를 提供해 주고 있다.

다음 石器面에서 보면 打製石器들이 主流가 되어 있으며 石質은 打製石器에서 흔히 볼 수 있는 火成岩이 大部分이며, 또한 近者 새로이 注意에 오르기 시작한 式[7]의 石英製石器가 出土되고 있어 注目을 끈다.

앞에서 言及을 하지 않았지만 圖 1에서 전경수 學友(一年)가 發見한 貝塚(×4)에서 出土된 骨角器 두 點은 蘇釜島 貝塚들의 價値를 한층 더 올려 주며 앞으로 좀더 正確한 學術的인 發掘이 要請된다 하겠다.

以上으로 보면 이 貝塚은 打製石器를 隨伴하는 陸地 傳來의 西海岸 櫛文土器系統의 文化라고 하겠으며, 年代는 時期가 좀 떨어지는 後期의 것이 아닌가 한다.

끝으로 本調査를 도와준 朴賢洙·朴鍾烈 等 여러 學友들께 感謝를 表하여 두는 바이다.

(1967. 6)

(7) 金元龍 : 前揭論文(註 6) p 39

究明해 보면, 于先 櫛文土器
그 中에는 列點文 아래에 斜
沙里 出土 斜交集線文과 共通
提供해 주고 있다.
質은 打製石器에서 흔히 볼
기 시작한 式(7)의 石英製石

發見한 貝塚(×4)에서 出
며 앞으로 좀더 正確한 學

西海岸 櫛文土器系統의 文
가 한다.
를 表하여 두는 바이다.

(1967. 6)

海外考古學研究所紹介 Ⅱ

MASCA(Museum Applied Science Center for Archaedogy)

考古學關係應用科學센터(略稱 MASCA)는 美國펜실바니아大學博物館에 있으며 1965年 2月에 創設되었다. 이 센터는 考古學研究에 있어서 새로운 技術의 試驗과 發展을 基本目的으로 하고 있으며 새로운 遺蹟遺物發見方法, 年代決定法, 正體把握法 및 解釋·評價法 등 廣汎한 分野에서 考古學研究法의 向上과 發展을 圖謀하고 있다. 또 考古學自體內에서의 그러한 方法들의 檢討뿐 아니라 다른 自然科學分野에서 發見되는 새로운 理論이나 技術 其他 知識이 考古學研究에 利用될 수 있는가 與否에 대해서도 銳利한 注意를 기우리고 있다.

펜실바니아大學博物館은 美國 大學博物館中에서도 代表的인 存在며 우르(Ur)를 비롯하여 近東地方遺蹟發掘을 通해서 蒐集한 尨大한 近東東關係蒐集品으로 有名하다. 이 博物館은 現在도 每年 10 乃至 15個의 野外發掘 및 調査事業을 展開하고 있으며 이 「마스카」의 創設도 그러한 活潑한 考古學的 事業遂行上의 必要에서 온 것이라 하겠다. 마스카는 當初에는 아스카(ASCA, Applied Science Center for Archaeology)라고 불리웠으나 ASCA라는 이름이 全혀 다른 性質의 어느 機關名으로 登錄되어 있기 때문에 머리에 Museum을 붙여 MASCA로 改稱한 것이다. 이 센터는 機構上 前記 大學博物館에 所屬되어 있으나 事務室은 同大學物理學科에 두고 있으며 所長은 Dr. Froelich Rainey, 副所長은 Miss Elizabeth K. Ralph, 그리고 따로 1951年 以來 開設된 放射性炭素年代決定實驗室이 이 센터創設과 함께 이리로 吸收되었다.

이 센터는 當分間 于先 考古學的踏査器具의 利用과 發展, 새로운 年代決定法의 調査, 既存 年代決定方法의 새로운 應用法, 各種分析方法의 調査, 그리고 情報交換센터의 設立등을 主要事業으로서 들고 있으며 이 마지막 事業의 시작으로서 Masca Newsletter를 年 2回發刊하고 있다. 이 뉴스레터는 28.5cm×21.5cm의 4折判 8面으로서 編輯擔當은 Miss Jeannette Flamm(主), Mrs. Ann M. Greene(助)이며 1965年 2月에 1卷 1號가 나온 以來 1967年 5月 3卷1號까지 나와 있다. 이 뉴스레터는 文字 그대로 얇팍한 레터形式이지만 內容은 上記 여러 分野에 있어서 世界各地의 最新 뉴스를 報道하고 있으며 考古學

研究法資料로서 莫重한 價値를 가지고 있다.

이 研究所의 住所는 다음과 같다.

Museum Applied Science Center for Archaeology
The University Museum
University of Pennsylvania
33rd & Spruce Streets,
Philadelphia, Pennsylvania 19104
U.S.A.

考古學關係英語選釋 Ⅱ

三佛

Layer 層, Stratum, 同一한 物質 또는 成分의 連續된 層, 例를 들면 粘土層, 礫石層, 混貝土層 등. 遺物包含層의 경우에는 人工層位가 아니고 自然層位를 말함.

Level 均層, 水平層, 水平으로 된 同 高의 面을 말하며 人工層位를 말할때 使用되나 同一文化層인 경우에는 表面의 水平與否에 關係없이 文化的 Horizon을 말하기도 한다. 例 Troy I, Troy II 등.

Micoquian 代表遺蹟 La Micoque (佛)에서. Acheulian의 最後段階로서 Core tool 系統.

Nodule core와 同義.

Nucleus(複數 Nuclei) Core와 同

Phase Complex와 同義. 다른 것과 區別될 수 있을 만한 文化的 要素(Traits)를 가지고 있는 어떤 複合體(Complex)

Scraper 掻削器 現代의 小刀처럼 쓰인 刃器, 石材, 刃의 位置, 性格, 形態 등에 따라 Core scraper, nose scraper, keeled or carinate scraper, end scraper, double-end scraper 등 各種이 있다.

Serrated blade 刃部가 鋸歯狀인 blade.

Seriation (順序配列) 여러 遺跡(또는 古墳)이 示現하는 遺物 構成相 또는 遺物形式 사이의 構成比率 등에 立脚하여 遺蹟사이의 相對新古序列을 定하는 것. 페트리의 이집트 古墳配列이 有名

Sondage 法 遺蹟에 위에서부터 바닥까지 트렌치를 넣어서 그 斷面相을 들어내는 方法.

Tempering 土器製作時 胎土에 補強劑로서 石粒 등 다른 物質을 섞는 것.

Terminus Post quem 上限年代

Tortoise-core 法 Levallois 石器工作의 特徵的 製作方法으로서 母石의 周圍에 몇개의 平行하는 Facet가 생기도록 打整하여 打擊面을 準備하고 거기서 楕圓形 가까운 scraper를 떼낼 수 있도록 마련한 것. 이 母石이 龜甲의 側面과 같다고 하여 Tortoise core라고 부른다.

Type 材料, 形態, 製作法 등 여러 面에 있어서 몇개의 뚜렷한 特性을 가지고 있는 構成體로서 다른 構成體와 區別될 수 있는 것.

1945年 以後 遺蹟發掘表

1946	(國 博)	慶尙北道 慶州市 路西里의 壺杅塚·銀鈴塚 發掘
1947	(國 博)	黃海道 開城附近 法堂坊에서 高麗古墳 發掘
1948	(國 博)	慶北 慶州市 皇吾里 古墳一基 發掘
1950~1951		6·25 事變으로 中斷
1952. 3.	(國 博)	慶北 月城郡 金尺里 新羅古墳 三基 發掘
1953	(國 博)	慶北 慶州市 路西里 137. 138號 墳 發掘
1954	(國 博)	韓國 西海 島嶼 調査
	(國 博)	鬱陵島 調査
1959	(國 博)	慶北 月城郡 外東面 感恩寺址 發掘
1959	(高 大)	慶南 熊川 貝塚 發掘
1960	(慶北大)	慶北 漆谷郡 仁同面 石室 古墳 一基 發掘
1960	(國 博)	全南 靈岩郡 始終面 內洞里의 一甕棺墓 發掘
1960. 12.	(國 博)	慶北 義城塔里 古墳 發掘
1961. 5.	(서울大)	京畿道 楊州郡 渼金面 水石里 先史住居址 發掘
1961. 6.	(高 大)	京畿道 慶州郡 九川面 明逸里 先史住居址
1961. 8.	(高 大)	慶南 昌原郡 熊川 子馬山 貝塚(二次)
1961. 10.	(國 博)	慶南 蔚山郡 溫陽面 三光里 古墳
1962. 1.	(國 博)	慶州 皇吾里 4.5 號墳
1962. 3.	(國 博)	忠北 堤川郡 淸風面 黃石里 支石墓
1963. 3.	(國 博)	慶北 迎日郡 杞溪面 文星里一帶 支石墓
1963. 6.	(國 博)	全南 光州市 忠孝洞 金谷里 麗末季初 陶窯址
1963. 6.	(仁川博)	京畿道 富川郡 永宗面 雲南里 支石墓
1963. 10.	(國 博)	忠南 天安市 斗井里 住居址
1963. 10.	(國 博)	京畿道 江華郡 一帶 支石墓
1963. 10.	(梨 大)	慶北 安東郡 一直面 松里古墳
1964. 2.	(國 博)	忠南 公州郡 鷄龍面 巢鶴里 百濟 盜堀 古墳
1964. 3.	(國	
1964. 3.	(慶北	
1964. 6.	(國	
1964. 7.	(高	
1964. 7.	(全南	
1964. 8.	(國	
1964. 9.	(梨	
1964. 9.	(國	
1964. 9.	(釜山	
1964. 10.	(서울	
1964. 10.	(東國	
1965. 4.	(延	
1965. 4.	(서울	
1965. 5.	(國	
1965. 6.	(慶熙	
1965. 7.	(慶熙	
1965. 8.	(慶熙	
1965. 8.	(文化財	
1965. 9.	(國	
1965. 12.	(文化財	
1966. 4.	(延	
1966. 5.	(國	
1966. 5.	(文化財	
1966. 8.	(國	
1966. 8.	(釜山大	
1966. 8.	(文化財	
1966. 8.	(崇實大	
1966. 10.	(서울大	

1964. 3. (國 博) 忠南 扶餘郡 恩山面 弩谷里 百濟 金剛寺址

1964. 3. (慶北大) 慶南 高靈邑 古衙洞 伽倻古墳

1964. 6. (國 博) 京畿道 坡州郡 月籠面 玉石里 住居址

1964. 7. (高 大) 慶南 昌原郡 熊川 子馬山 貝塚(三次)

1964. 7. (全南大) 全南 潭陽郡 水北面 寒水洞 李朝 窯址

1964. 8. (國 博) 慶北 月城郡 內南面 上幹里 支石墓

1964. 9. (梨 大) 慶北 安東郡 臥龍面 古新里 古墳

1964. 9. (國 博) 慶南 康津郡 大口面 沙堂里 高麗 窯址

1964. 9. (釜山大) 慶南 金海郡 酒村面 農所里 貝塚

1964. 10. (서울大) 서울特別市 城東區 風納里 百濟土城址

1964. 10. (東國大) 忠南 扶餘郡 石城面 縣井里 所在 百濟 臨江寺址

1965. 4. (延 大) 忠南 公州郡 石壯里 舊石器

1965. 4. (서울大) 慶北 月城郡 望星里 新羅窯址

1965. 5. (國 博) 京畿道 坡州郡 德隱里 및 多栗里의 支石墓群

1965. 6. (慶熙大) 京畿道 廣州郡 道馬里의 李朝初期 窯址

1965. 7. (慶熙大) 慶北 義城郡 金城面 大里 古墳發掘

1965. 8. (慶熙大) 全南 各城郡 拱北里 支石墓

1965. 8. (文化財管理局) 慶州市 古新羅 古墳

1965. 9. (國 博) 全南 康津沙堂里의 青磁窯址

1965. 12. (文化財管理局) 慶州市 芬皇寺址內에서 石佛群 發掘

1966. 4. (延 大) 忠南 公州郡 石壯里 舊石器遺蹟

1966. 5. (國 博) 京畿道 江華 三巨里 支石墓

1966. 5. (文化財管理局) 全南 益山 彌勒寺址發掘

1966. 8. (國 博) 全北 扶安郡 保安面 柳川里 陶窯址

1966. 8. (釜山大) 釜山市 多大浦貝塚

1966. 8. (文化財管理局) 慶州 皇吾里 古墳 1, 32, 33, 34號 發掘

1966. 8. (崇實大) 서울市 城東區 驛三洞 先史住居址

1966. 10. (서울大) 全南 西部 島嶼 遺蹟 調査

1966. 11. (서울大) 全南 西部 島嶼 二次 調査

1966. 12. (서울大) 慶南 東萊郡 西生面 新岩里 先史 遺蹟 一部 調査

1967. 3. (서울大) 南海 島嶼 調査(三次)

1967. 7. (慶熙大) 서울市 城東區 岩寺洞 櫛文土器 住居址

1967. 7. (檀國大) 慶南 泗川郡 西浦面 舊坪里 貝塚

韓國 考古 뉴스

國內

○韓炳三「日本에 있어서의 考古學」

서울大學校 考古人類學會에서는 지난 1967年 3月 31日(金) 文理大 本 10講議室에서 學術發表會를 開催하였든 바 校內學生과 多數의 關係人事가 參席盛況裡에 끝났다.

○松原 三郎 敎授 「韓國의 佛敎彫刻」

訪韓中인 松原敎授를 맞이하여 서울大學校 考古人類學會에서는 지난 5月 16日 文理大 講堂에서 約 2時間에 걸친 講演會를 가졌었다. 通譯은 國立博物館의 金正基先生이 手苦하여 주셨다.

○梅原 末治博士 講演

지난 5月 20日 高大 亞細亞問題 硏究所의 招請으로 來韓하였던 梅原氏는 同大學에서 「東亞考古學의 諸問題」라는 題目으로 講演하였다.

○第十回 歷史學大會

지난 5月 26日 27日 兩日間 建國大學校 講堂에서 열린 第10回 歷史學大會에서 考古美術에 關한 다음과 같은 發表가 있었다.

金基雄「日本古墳에서 본 韓國的性格」

蔡秉瑞「高句麗時代의 古墳壁畵에 나타난 服飾攷」

○全南大 開校 十五週年 記念 講演會

지난 6月 13日 全南大學校에서 同校 開校 記念行事의 하나로 다음과 같은 講演이 있었다.

李弘稙「古代國家成立과 百濟」

黃壽永「新羅文武王陵의 調査」

秦弘燮「新羅皇龍寺址 舍利孔의 調査」

○風納里土城內出土 木炭年代

1964年에 發掘한 風納里土城內包含層 F 핏트 下層에서 나온 木炭을 東京大學 泉靖一교수의 周旋으로 東京理化學研究所에 年代調査依頼中이던 바 7月 中旬 回答을 받았으며 그 結果는 1770±120B.P이었다. 한편 함께 提出한 梁山貝塚(1965年 發掘)의 木炭(下層)은 2例가 1800±120, 1890±120이라는 結果를 내었다.

○金銅菩薩立像 發見

지난 1月 24日 서울市 城北區 三陽洞山 108에서 下水道를 파다가 朴龍出氏에 依하여 發見되었는데 이는 三國末의 作品으로 國寶로 指定 文化財 管理局에 保管中이다.

○金銅佛 出土 2例

① 韓國日報 2月 26日字에 依하면 慶南 咸安郡 北面 舍村里에서 朴鍾洙氏가 金銅佛 1個를 發見하였다고 하는데 新羅時代의 小立像이다.

② 東亞日報 3月 10日字에 依하면 높이 28.3cm의 高麗時代 金銅如來立像이 慶南山淸郡 新等面 長川里 雲龍寺址에서 出土되었다고 한다.

○泗川郡內의 支石墓群·貝塚發見

지난 2月 24日과 25日 兩日間 朴敬遠·金相朝兩氏에 依하여 다음과 같은 先史 遺蹟이 發見되었다.

○泗川郡 正東面 所谷里	支石墓群
○泗川郡 西浦面 大浦里	貝塚
○泗川郡 泗南面 陵花里 및 兵屯里	支石墓群

○南海島嶼의 考古學的 調査

金元龍교수는 1966~1969年까지 3個年 計劃으로 南海에 散在한 諸島嶼를 對象으로 先史~歷史時代遺蹟遺物의 調査를 進行中인바 그 全體的인 計劃 및 이미 3回에 걸친 一次年度의 調査結果는 下記와 같다.

(ㄱ) 調査期間 1966~1969(三年間)

(ㄴ) 調査隊……金元龍, 任孝宰, 金東賢外 學生

(ㄷ) 調査對象……全南 慶南의 南海島嶼中 先史, 歷史時代의 一切 遺蹟, 遺物

(ㄹ) 調査方法

第一年—全南 西部島嶼에 대한 地上分布調査

第二年—全南 東部島嶼에 대한 地上調査 및 第一年度 調査分의 重要 遺蹟 發掘

第三年—慶南地區 島嶼의 分布 調査 發掘, 全南 東部 島嶼 重要遺蹟發掘

第一次年度 調査 結果

全南에 屬한 40個의 島嶼의 地上 調査 結果 다음과 같은 새로운 遺跡을 發見하였다.

一回 1966. 10. 20—11. 6(全南西部)

二回 1966. 11. 11—11. 22(〃)

三回 1967. 3. 12—3. 23(〃 東部)

石器時代貝塚	6
支石墓群	4
石器採集地	4
三國時代 遺跡	2

○支石墓 發掘

國立博物館에서는 昨年에 이어 江原道 春城郡 新北面 泉田里 支石墓의 二次 調査(1667. 3. 31—4.15)를 實施하였는데 그 內部 地面에서 無文土器와 櫛文土器片이 出土되었다고 한다.

○高麗鐘 發見

京畿道 驪州郡 金沙面 上品里 一名「바니골」에서 밭갈이 하던 一農夫에 依하여 高麗初期(文宗 12年)의 鐘이 놋그릇 12個와 함께 發見되었다. 上部의 直徑은 38cm 下部는 53.5 cm 두께는 3.5cm 높이 81.5cm 이며 五行 三十字의 陰刻銘文이 있다.

○府院洞 貝塚 發見

慶南 金海邑 府院洞에서 金海~古新羅時代에 屬하는 100餘點의 土器가 貝塚에서 出土

되었다. 이는 包含層의 範圍가 相當히 넓은 큰 貝塚으로 金海 會峴里 貝塚과 마주 보고 있는데 앞으로 釜山東亞大學에서 發掘을 計劃中이라고 한다.

○支石墓群 發見

本科 任孝宰助敎는 지난 4月 20日~4月 30日까이 全南 順天市 附近의 地上 踏査에서 多數의 支石墓群을 發見하는 以外에 따로 30cm의 磨製石未成品 一個와 金海土器 若干을 採集하였다.

(1) 全南 昇州郡 別良面 石峴……支石墓群 立石
(2) 全南 昇州郡 海龍面 弄珠里……支石墓群
(3) 全南 〃 〃 福星里…… 〃 〃
(4) 全南 光陽郡 光陽 回岩……磨製石劒未成品, 金海土器

○新羅 文武王陵 調査

韓國日報主管「新羅五岳調査團」은 5月 16日 月城郡 陽北面 奉吉里 무점부락 海中에 자리잡은 大王岩을 調査하여 이것이 新羅 第30代 文武王陵이라고 발표하였다.

이 大王岩은 內部에 東西南北으로 뚫린 十字形 연못이 있으며 그 中央에 大石이 沈下되어 있으며 이 大石밑에 文武王의 遺骨이 藏置되어 있는 것이라고 믿어진다.

○德積島 先史貝塚 發見

지난 1967. 6. 6~6. 9까지 서울大學校 考古人類學科生 20餘名은 京畿道 富川郡 德積島內를 調査中 德積島 鎭里 附近에서 20×20 평방미터에 達하는 先史 貝塚과 보다 작은 貝塚 一個를 發見하였다. 이 以外에도 이 島嶼와 隣接된 蘇爺島에서도 櫛文土器系統의 土器를 出土하는 새로운 貝塚 2個를 發見하였다.

○東萊貝塚 發掘

1967. 6. 16~7. 29까지 國立博物館에서는 慶尙南道 林木種苗場內의 貝塚을 發掘 調査하였다. 尹武炳學藝官 主査로 實施된 發掘에서 多數의 金海式土器類와 紡錘車 骨針 獸骨等이 出土되었으며 爐址로 推定되는 遺構도 發見되었다. 來年에 再次 發掘할 計劃이라고 한다.

○濟州道의 考古學的 調査

美國 하와이 大學助敎授인 R. Pearson과 서울大 任孝宰 兩氏는 濟州道의 考古學的 調査를 目的으로 지난 6月 28日~7月 13日까지 近 보름간 島全域에 걸친 地上調査를 끝냈다.

그 結果 吾羅洞에서 磨製 石刀를 비롯한 打製石斧, 土器等을 發見하였고 光令 高內 高山等地에서 새로운 遺蹟(包含層)을 發見하였다.

(磨製石刀는 濟州道 民俗博物館에 陳列品이며 그 以外에 十餘點의 打製石斧는 서울大 博物館에 保管中이다)

○城東區 岩寺洞 爐址 生居址 發見

지난 7月 14日 慶熙大 金基雄敎授에 依하여 城東區 岩寺洞에서 先史時代의 爐址·住居址가 確認調査되었다.

이곳은 C中高校가 野球場을 만들기 爲하여 불도-저를 約 一萬坪쯤 정지 作業을 해 놓은 곳에 露出된 것으로 現地表로부터는 1m 80cm下에서 都合 5個의 爐址를 確認하는 한편 多數의 櫛文土器片과 石斧, 石鏃, 石錐等 10餘點의 石器를 採集하였다.

○慶州市內 古墳發掘

文敎部 文化財 管理局의 主管으로 實施되는 慶北市內의 廢墳 整理 事業이 今年에도 7月 17日~8月 3月日까지 계속되었다. 發掘에는 梨大·慶北大·서울大가 參加하였으며 그 對象은 古新羅時代의 積石木槨墳이다.

○慶南 泗川郡 西浦面 舊坪里 貝塚發掘

檀國大學校 博物館(館長 鄭永鎬교수)에서는 지난 7月 17日부터 27日까지 大浦里 貝塚을 發掘하였는데 1m가 넘는 包含層에서 여러 種類의 櫛文 土器 文樣 破片이 採集되었고 石器·骨器도 採集되었는 이는 釜山市의 東三洞·多大浦 貝塚과 비슷한 性質의 貝塚으로 이 地方 先史 文化硏究에 重要한 遺蹟의 하나이다.

海外

두개의 考古學關係 定刊誌 出刊

Prespezioni Archeologiche

「考古學踏査」라고 題하여 1966年에 第1號가 나온 이 定刊誌은 이태리 로마의 레리치 財團(Fondazione Lerici)에서 發刊하는 것이며 年 1册 乃至 2册 刊行될 豫定이다. 이 雜誌는 그 目的이 創刊人事편지에 依하면 "dedicated to the modern applications of science and technology to archaeological prospecting"이라고 되어 있다. 即 考古學研究法에 있어서도 野外에 있어서의 遺蹟遺物踏査法(發見法)을 그 對象으로 하고 있으며 앞으로 野外調査에 있어서 調査法의 實質的 應用, 또는 그 理論的, 實驗的 研究에 關해 全世界의 專門家들로부터 原稿를 받아서 실릴 計劃이라고 한다.

四折本 本文 87, 圖版 26의 第1號는 1965年 4月 로마에서 레리치財團 創設 10 週年記念次 열린 考古學踏査新方法 國際심포지움에서의 發表의 要旨들을 그대로 集錄한 것으로 그 目次를 轉載하면 다음과 같다.

A. Hesse: The importance of climatologic observations in archaeological prospecting.

C. Colani: A new method and wide-range apparatus for locating metal objects in the ground, fresh water and salt water.

E. Carabelli: A new tool for archaeological prospecting: the sonic spectroscope for the detection of cavities.

R.E. Linington: Test use of a gravimeter on Etruscan chamber tombs at Cerveteri.

I. Scollar: Recent developments in magnetic prospecting in the Rhineland.

J. Alldred, M.J. Aitken: A fluxgate gradiometer for archaeological surveying.

L. Langan: Use of new atomic magnetometers in archaeology.

M.J. Aitken, J. Alldred: Prediction of magnetic anomalies by means of simulator.

R.E. Linington: Further examples of the use of simplified theoretical anomalies in magnetic surveying.

그리고 이 定刊誌의 住所는 다음과 같고 誌代는 年 10弗이다.

Prospezioni archeologiche
Roma, via Veneto 108
Italy

考古學ジヤーナル

英名을 The Archaeological Journal이라고 하는 이 月刊誌는 日本 東京 ニュー・サイエンス社에서 發刊하는 것이며 1966年 10月에 第1號가 나왔고 現在까지 每月 1册씩 合 9册이 나왔다. 이 雜誌는 江坂輝彌(慶應大學考古學研究室), 芹澤長介(東北大學日本文化研究所), 坂詰秀一(立正大學考古學研究室) 諸氏가 編輯委員으로서 딱딱하고 專門的인 것이 아니라 啓蒙的이고 敎養을 위한 가벼운 考古學關係글들을 싣고 있으며 日本의 考古學界動向에 關해서 仔細한 뉴스를 提供하고 있으나 海外考古學界에 대해서도 많은 關心을 가지고 있다. 雜誌는 46倍判 30~40面정도의 小册子이며 每號定價 200圓, 1年分은 2160圓으로 되어 있고 住所는 東京都千代田區神田神保町 1~24 ニューサイエンス社이다.

新 刊

○서울大學校 考古人類學科 叢刊 第Ⅱ册 風納里 包含層 調査 報告

金元龍著 4·6倍版 本文 46頁 因版 18 서울大 出版部 印刷

○考古美術資料集 考古美術 同人會刊

第十二輯 然齋考古論集 洪思俊著

第十三輯 韓國石燈目錄 鄭明鎬編

第十四輯 韓國塔婆研究各論草稿 高裕燮編

第十五輯 續金石遺文 黃壽永編

金載元 「松林寺磚塔」 震檀學報 29. 30合併號 1966. 12

金元龍 「天安市 鳳龍洞山上 無文土器 遺蹟」 震檀學報 29. 30合併號 1966. 12

〃 「雄基 屈浦里 西浦項貝塚의 遺物」 歷史學報 32輯 1966. 12

〃 「水石里出土의 黑陶小壺」 韓國考古 1輯 1967. 1

〃 「韓國考古學界 20年」 考古學ジヤーナル 5號(日本) 1967. 2

〃 「韓國江原道襄陽郡出土 細形銅劍細文鏡に ついて」 史林 50卷 2號(日本) 1967. 3

尹武炳 「韓國 靑銅短劍의 型式分類」 震檀學報 29. 30合併號 1966. 12

崔淑卿 「永宗島 雲南里 支石墓」 金愛麻先生梨花勤續四十周年記念論文集 1966. 12

任孝宰 「箕佐島 支石墓群」 韓國考古 1輯 1967. 1

金鍾澈 「廣州渼沙里 櫛文土器遺蹟에 對한 小考」 韓國考古 1輯 1967. 1

崔夢龍 「靑鶴里 粉靑砂器窯址」 韓國考古 1輯 1967.

〃 「郭支里 支石墓 踏査報告」 文理大 學報 13卷 1.2合併號 1967. 3

蔡秉瑞 「安岳地方의 壁畵古墳」 白山學報 第二輯 1967. 5

文明大 「韓國石窟寺院의 研究」 單行本(油印) 1967. 3

서울大 考古 人類學科 第三回生(1967. 2)卒業 論文

柳仁子 「三國時代 曲玉에 關한 研究」

康信敦
蔣正幸 「在京 以北人 生活에 關한 研究」
鄭永浩

動 靜

○本科 人類學 擔當敎授로 韓相禧先生 就任(1667. 3)

○第一回卒業生 權彝九氏 同科 助敎로 就任(1967. 3)

○第三回卒業生 柳仁子 서울大博物館 學藝士 就任(1967. 3)

○金健(二回) 서울 新聞社 記者로 就任

○金元龍교수는 1967. 7. 9~15까지 日本 立敎大學에서 「韓國古代文化」에 關한 集中 講義

○三回卒業生 安輝濬 Harvard大學校 大學院에 入學次 渡美(7月)

○任天彬(一回)氏는 文化財委員會職員으로 就任(7月)

○鄭永和(一回)氏는 國立博物館見習職員으로 就任(8月)

○姜泳哲(二回) 和祥羅紗(鍾路二街 파고다극장 옆) 開業

來韓外國人學者

○坪井良平(梵鐘研究家)·梅原末治(考古學者)·松原三郎(佛敎彫刻研究家) 諸氏 訪韓(5月)

○R. Pearson(하와이大學 人類學科助敎授 6月)

受贈　交換圖書

國　內

美術資料	9. 10輯	國立博物館
線友會報	8. 9輯	梨大 社會生活科
社會學報	8. 9輯	서울大 社會學科
震檀學報	25,26,27,28,29,30	震檀學會
業蹟報告書		東亞文化研究委員會
東亞文化	4,5,6輯	東亞文化研究所
駱山語文	創刊號	서울大國文科
歷史學報	31,32,33輯	歷史學會
韓國考古學概論		金元龍
地質鑛床	1, 2號	國立地質調査所
地質鑛床調査報告	8號	〃
炭田地質 〃	5號	〃
地下水源調査報告	2號	〃
韓國經濟關係文獻集成		東亞文化研究所
文理大學報	第十三卷 1.2合併號	서울大學生會
新羅伽倻文化	第一輯	靑丘大
分類別 洋書目錄		서울大
文化財	第二號	文化財管理局
電氣通信事業八十年史		遞信部

海　外

考古學雜誌	52卷 1,2,3,4號	日本考古學會
邊政學報	第四期	中國政治大學
中國學報	第四輯	韓國中國學會
日本文化研究所 研究報告	1,2	日本文化研究所(東北大學)
考古學ジヤーナル	創刊號	日本ニューサイエンス社
朝鮮研究年報	第八號	三品彰英編
考古人類學刊	第27期	臺灣大
史林	50卷 2號	日本京都大學

○Artibus Asiae	New york 大學校
○Current Anthropology	美國

○Pattern and Process in the Early Intermediate Period Pottery of the Central Coast of Peru (Publicatins in Anthropology vol 3)·····California 大學校

○Anthropological Records Vol. 23·····California 大學校

○Anthropological Records Vol. 24·····California 大學校

○Archreology of the Point George Site and Tolowa Prehistory·····California 大學校

○Early Culture and Human Ecology in South coastal Guatemala·····Smithsonian Institution

○Smithsonian Contributions to Anthropology Vol. 2 No 2,3,4 〃

○The Israel Museum News·····Israel Embassy

購 入 圖 書

○Anthropology Today

○W. L. Libby. Radiocarbon Dating

○I.C. Jarvie. The Revolution in Anthropology

○L. Clark. Archreology and Society

○B. Campbell. Human Evolution

○壺杆塚斗 銀鈴塚 (國立博物館 古蹟 調査報告 第一册)

○大正十一年 度古蹟調査報告 第二册(南朝鮮に於ける 漢代の 遺蹟)

韓國 考古 第二輯 發行 贊助 芳名

實習費	補助	10,000	金光彦	(二回)	1,000
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同 6,000
2,000

47,000

西紀 1967年 9月 25日 印刷
西紀 1967年 9月 30日 發行

韓國考古

〈第2輯〉

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It would seem that archaeologists and anthropologists have enough to do without worrying about things like rising labor costs, the population explosion, and urban sprawl.

But scientists at the University of Pennsylvania Museum's Applied Science Center for Archaeology (MASCA) are much concerned about these trends for good reason-- more people and bigger cities threaten the destruction of major, unexplored archaeological sites. And from an economic standpoint, rising labor costs make starting a dig impractical unless there is some guarantee of finding something meaningful.

Faced with this dilemma of speeding up research while holding down costs, MASCA has, in recent years, become the leading source of new scientific tools for archaeological prospecting.

Over the last two years, the National Science Foundation has awarded MASCA $249,000 in grants supporting the improvement of techniques which have revolutionized the work of archaeologists in the field and laboratory. These techniques, based on fundamental principles of physics, chemistry, and other sciences, include remote sensing and detection of buried cities and roads through satellite, aerial and balloon photography; near sensing with electronic devices to

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pinpoint underground walls, buildings and caves; chemical techniques to identify and classify elements and compounds basic to certain artifacts; and most importantly of all, the actual dating of ~~objects~~ appropriate and ~~anthropological~~ archaeological remains through complex analysis of their radioactive levels.

Two recent important sites that have been located and investigated ~~more thoroughly~~ with the help of these new methods are the fabulous lost Greek city of Sybaris, in southern Italy, whose limits, buried under 20 feet of earth and mud, were mapped with the help of a device called a cesium magnetometer. Archaeologists had sought Sybaris in vain for nearly 100 years until MASCA entered the picture.

~~Last year,~~ Part of the submerged city of Halieis, ~~550 yards off~~ on the coast of southern Greece, was ~~located~~ photographed under six feet of water by radio-controlled cameras suspended from ballons. ← or "mapped"

In these and other cases, several technological techniques are used to check on and verify each other. Roman ruins under a farmer's field in Kingscote, England, for instance, were initially detected through careful examination of ~~special~~ aerial photographs. Later, a magnetometer survey at ground level corresponded beautifully with the photographic information.

MASCA's keystone, however, is its Radiocarbon Laboratory, which has ~~verified~~ provided the dates of more than 2,000 ~~artifacts~~ samples from over 200 archaeological sites since 1951. By measuring residual amounts of radioactive carbon-14 ~~remaining~~ in ~~objects~~ samples from sites of antiquity, the laboratory has established chronologies for the Near East and Mediterranean regions, the Arctic, and Central and South America-- ~~the~~ four of the most important main archaeological anthropological areas of the world.

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[four of the most rigorously investigated archaeological areas]

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With the advent of thermoluminescent dating, which MASCA helped develop, even inorganic materials such as fired pottery, became datable in archaeological terms.

~~Roughly similar,~~ these two dating techniques have rewritten archaeological history in the last 20 years by eliminating the guesswork about dates and places of origin. Carbon 14 exists in all organic ~~material~~ and begins to decay at a fixed rate when ~~a substance~~ dies. After some 5,730 years, give or take ~~40~~, only half the original amount of carbon 14 ~~will~~ remain. How much is actually present at any given time lets the scientist calibrate when death occurred, and thus the historical date of the object and other materials discovered with it.

Thermoluminescence tells the scientist when a given piece of pottery was fired through the ~~radioactive~~ glow it gives off when reheated under special conditions. ~~How much it~~ glows indicates how much time has passed since the pottery was fired.

Both these techniques have their limitations, of course, but MASCA scientists are cooperating with their colleagues around the world to perfect them and iron out discrepancies.

Through its Information Center, MASCA collects, publishes, and distributes archaeological and anthropological knowledge gathered from literature, field surveys, excavations, and laboratory experiments carried out throughout the world. Today, thanks to MASCA and laboratories like it, fewer and fewer scientific expeditions are being forced to work in the dark through educated guesses, and the high number of important sites uncovered in recent years is ample testimony to the accuracy of MASCA's methods.

Dr. Pepper's appeal was supplemented by the declarations of prominent manufacturers in various parts of the country and by an official statement of the organization and practical workings of the Museums. Undoubtedly the argument which carried the most weight was concerning the nature of the Museum itself: that it was a public institution, organized, controlled, and supported by the city of Philadelphia, and that it was conducted entirely for the benefit of the public. In 1898 the city of Philadelphia appropriated $100,000 for the maintenance of the institution, and on the 21st of December of that year Congress appropriated $50,000 for the collection of foreign trade samples. The appeal to Congress met with further success: it appropriated $300,000 additional, which was expended principally in the erection of the Exposition Building.

Down to the close of the fiscal year, 1899–1900, not less than $1,455,000 had been appropriated for the use of the Museum by the city of Philadelphia, the State of Pennsylvania, and the national government. Of this amount the city had contributed more than $1,000,000, in addition to its donation of fifty-six acres of land within the city limits for the permanent buildings of the Museums.

From the outset the plan of the institution included the organization of a domestic advisory board, whose members were elected by chambers of commerce, boards of trade, and other commercial bodies throughout the United States. The first meeting of this board was held June 3, 1896, when nearly one hundred organizations were represented. On this occasion Dr. Pepper, as president of the Museum, entering at length into details, explained its scope and purpose as follows:

"It is proper that, before proceeding to the business of the morning, a brief statement shall be made of the scope and intent of the movement we are initiating.

"While barter and trade are found in primitive stages of human development, commerce is a function of highly organized society. Its extent and character give unerring indications of the power and importance of communities. The methods by which it is conducted and the influence by which its permanence is ensured, its growth promoted, and its advantages diffused, are subjects of profound interest and practical importance.

"Naturally, there have been developed agencies of various types for the investigation and advancement of commercial interests. The organization of the individual trades, the Trades League, the Board of Trade, the Chamber of Commerce, each deals with a special phase of the subject. These concern themselves solely or chiefly with practical results, and are unavoidably influenced by the influential interests of the locality or the industry represented.

"It would seem clear, however, that no method of studying industries and commerce can be scientific and complete which does not include the museum idea, as now comprehended. The Museum aims to teach by object-lesson the story of the world, past and present. The Biological Museum presents the objects of human and comparative anatomy, arranged scientifically and labelled so fully as to constitute the best text-book for the study of those subjects. The Museum of Natural History does the same in its field. The Museum of Archæology shows the progress of the race from the most archaic times, the different types of human beings, their modes of living, their forms of worship, their games, their weapons, their implements, the natural products which they use for subsistence, in their industries, and in their arts, the objects of manufacture or of art which they produce, and the manner in which they dispose of their dead.

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complete Museum comprehends not only the above but many other special collections, whether installed under a single management or distributed more or less widely.

"It is not too much to assert that the level reached in intelligence and organization by any community may be gauged most accurately by the attention and support of its museums.

"Some years ago we began the serious task of developing in this community a complete series of museums. The controlling purpose has been the embodiment in each of the strict scientific and educational method. This implies the creation of a staff of experts of professional rank, the establishment of laboratories for original investigation upon objects forming the collection, the formation of a library of reference and of a bureau of publication to diffuse the results attained.

"The natural products and manufactured articles which constitute the material of commerce came necessarily into such a scheme, and the long-looked-for opportunity of establishing a commercial museum upon a truly scientific basis presented itself when, at the close of the Columbian Exposition at Chicago, it was possible, through the enlightened liberality of the municipal authorities of Philadelphia, and the invaluable services of Professor W. Powell Wilson, to secure vast collections of commercial material. The problem which gave gravest anxiety was to secure a form of organization which would preserve the administration of the proposed museum from the taint of personal interest, would foster a true scientific spirit in all its work, and would secure a permanent financial stability.

"The necessary legislation was secured which called into existence a Board of Trustees, recognized officially and legally as a department of the city of Philadelphia, and the mode of whose appointment is such as to justify the hope that at all times practical educators and scientific museum experts will be found associated with the leading men of affairs.

"So conclusively satisfied have the municipal authorities been

from the outset as to the disinterestedness of all connected with this important movement, that already, under two successive administrations, large appropriations have been made for the maintenance and development of the Museums; and a valuable tract of land has been transferred to the Board of Trustees as a site for the permanent fire-proof buildings, upon the construction of which we hope soon to begin.

"It is needless to say that this official and disinterested character alone has justified recognition by the State authorities, whose active co-operation has been constantly available and whose approval has been announced, of the policy that the State should contribute her share to the development and maintenance of this institution.

"An equally gratifying result has been the recognition of our work by the national authorities. No matter how extensive our collections might be, their value would be sadly impaired unless the Museum should maintain a Bureau of Information, prepared to issue the most full, recent, and accurate information upon each and every commercial subject. The late Mr. Gresham, when Secretary of State, extended to us the most encouraging assurance; and his eminent successor, the present Secretary of State, has graciously placed the Museum administration in relation with our consular service in a manner which seems sure to confer important reciprocal advantages.

"A library containing files of over five hundred trade journals, embracing nearly all of importance published, together with full sets of the official publications of the leading countries of the world relating to commerce; special consular reports, prepared in response to our printed sets of questions forwarded by the Department of State; full reports from our own agents sent to localities of particular importance; a force of clerks familiar with the languages of the leading commercial countries, constantly engaged in the preparation of fresh and accurate bulletins: these constitute the equipment of the Bureau of Information.

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serviceable to every manufacturer and commercial concern in the country which desires to be qualified to share in our growing export trade. It is our purpose to render equally serviceable the collections which illustrate these circulars; for these collections will be kept continually up to date by the co-operation, of which we have already cordial assurance, of special commissions appointed in the various countries with which we aim to have important commercial relations. Note, for instance, the object-lesson here afforded by the treatment of the exports and imports of Venezuela. We have been happy to serve the National Association of Manufacturers by securing a concession for the establishment of a bonded warehouse in Caracas for the display of American manufactures. In our Museum here are displayed all the natural products of Venezuela, scientifically arranged and classified, and clearly labelled and described; and in an adjoining series of rooms are arranged the leading manufactured articles imported from Europe into Venezuela. These samples have been recently purchased by our representatives, who went abroad for this special purpose.

"It was only after having demonstrated the public confidence in the integrity of our purpose and in the strictly scientific method of our work, and after having secured the above-mentioned relation with our consular service, and after having formed collections which may fairly be described as unequalled in many lines, that we felt prepared to take the final step in organization, and to propose the formation of a national advisory board.

"It is possible that mere courtesy and transient interest in a novel experiment might have won for this proposal some favorable recognition. But it is obvious that to have received a prompt and favorable response from every commercial organization, embracing many of the most important in the country, to which invitations were extended, to have learned that in every instance the delegates chosen have been of the most distinguished and representative class, and to now welcome here so many of those appointed, implies a belief that this institution is prepared to render substantial and

enduring service to the commercial interests of the entire country.

"This service will consist, in the first place, in the opportunity afforded to the individual members of your constituencies to secure the advantages of the Bureau of Information, and to profit by our great collections from reports of agents sent here to study them. But, again, we shall maintain a regular official relation with the organizations from which you come to us as delegates by providing a free series of monthly reports upon trade conditions. It shall be our aim to render these more fresh, full, and accurate than could otherwise be obtained. We shall further send not only the annual reports and the official catalogues to the commercial organizations as a body, as well as to the delegates as individual members of our Advisory Board, but also all reports from our laboratories, where scientific investigations are to be conducted upon the extensive series of products gathered from all sources.

"But even more than upon the value of these reports and contributions to the bodies which you represent do we depend upon the actual practical value of the meetings of the Advisory Board. It is our belief that these meetings should be strictly business meetings, devoted to the presentation and discussion of commercial topics in a serious and scientific spirit. Products, facts, and processes, not theories, or doctrines, or politics, should be the subject-matter of our deliberations.

"At the close of these remarks I shall ask your permission to appoint a Committee on By-laws and Programme of Business for future meetings, and will request them to report at the opening of the afternoon session. I shall then invite a most full and free discussion of the organization and plans of the Museum, in order that valuable suggestions may be received as to the manner in which this Museum may be enabled to best serve the manufacturing and commercial interests of the entire country.

"The trustees and officers of this Museum ask for your confidence in their freedom from local or political or *doctrinaire* views.

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They approach this great work from a purely scientific and educational stand-point, believing that thus the highest standard of activity will be maintained and the best results be accomplished.

"Philadelphia has surely done nobly, and well deserves the large measure of approval and of substantial benefit which will accrue from the development of this national institution in this locality. If the happy balance now adjusted can be maintained, and the material support be provided by the city and State in whom the property of the institution will vest, and to whom inevitably will accrue a rich return for the liberal services made, while the recognition and facilities extended by the national government confer unique privileges, and the Bureau of Information is rendered self-supporting by individual subscriptions, and the official relations of the Museum with the commercial organizations throughout the country is assured by our Advisory Board, it would seem not improbable that far-reaching results may follow our efforts to promote the commercial prosperity of our country."[1]

Plans were now perfected for the extension of the work of the Museum abroad and for the utilization of the institution by business houses in the United States. It was decided to enlarge the membership so as to include all countries in North and South America, and extensive preparations were made for the next annual meeting of the Board.

The reputation of the Museum was already so great that when its director and the chief of its Scientific Department went to Mexico, in the spring of 1897, for the purpose of awakening an interest in the approaching gathering, and in the work of the Museums generally, they found that the reputation of the Museum had preceded them. President

[1] Proceedings of the First Annual Meeting of the Advisory Board of the Philadelphia Museum, June 3–4, 1896, 22 pp. Philadelphia *Press*, June 3, 1896.

Diaz received them most courteously, expressed his warm personal interest in the object of their mission, and surrounded them with opportunities for insuring success. When the delegates assembled at Philadelphia in June, 1897, it was discovered that the membership of the Advisory Board had increased fifty per cent. during the year and that sixteen countries were represented. The delegates from Mexico and Brazil were appointed by the chief executives of these countries. The gathering took on a much broader character than the one of the previous year, and was known as the Pan-American Commercial Congress. At the second day's session the President of the United States, William McKinley, made a memorable address formally inaugurating the Museum as a public institution. His remarks met with enthusiastic approbation, when he said:

"The avowed aim of the Philadelphia Commercial Museum is to aid in the development of commercial and industrial prosperity. No worthier cause can engage our energies. It is a most praiseworthy one,—the extension of trade,—and is to be followed by wider markets, better fields of employment, and easier conditions for the masses. Such an effort commands instant approval of all, for it is linked with the prosperity of the humblest toiler and the welfare of every home and fireside. Its generous support will insure and increase its usefulness. A spirit of friendly and mutual advantageous interchange and co-operation has been exemplified which is in itself inspiring and helpful, not only to trade and commerce, but to international comity, and good-will must always precede good trade. The purchasers and consumers of all nations are here brought together in close touch and taught to work together for the common weal. A movement of this kind is national,—aye, more than that, international in its character; and I predict that its success will surprise even its most enthusiastic friends and founders."

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Only those who have participated in working out the details of such a gathering as this to which the President of the United States was here speaking can appreciate the enormous labor involved in the successful carrying out of such an undertaking. The burden of the work fell upon Dr. Pepper. It was he who wrote the draft of the letter of invitation sent to the President of the United States, and it was he who determined the form and style of every important feature of the meeting.[1] He was no longer Provost of the University of Pennsylvania, but retirement from that honorable office had in no wise decreased his influence or diminished his fame. He was still the foremost citizen of Philadelphia.

Nothing delighted Dr. Pepper more than to be able to participate in a public movement of acknowledged usefulness. He loved to touch elbows with men of affairs, and he had profound respect for the captains of industry whose services all over our country have contributed to make it what it is. He knew very well that the business men who had assembled from so many countries to participate in this meeting of the Advisory Board represented substantial interests of the world. He felt that he was directing his energies in channels of even greater utility than the limited domain of academic effort.

During the session many interesting reports and speeches were made. It was decided unanimously that the privileges of membership in the Board should be extended to Australia and to the countries of Asia and Africa. The delegates from Mexico and Central South America referred to the efforts of James G. Blaine to bring the people of North and South

[1] MS. letters, Dr. Pepper to Dr. Wilson, in the Archives of the Philadelphia Museum.

America into closer commercial relations. The word reciprocity was on every lip, and commercial harmony was the common thought. Every part of Latin America was found to be friendly to the United States. Other nations and other races might be our competitors, and in some instances our bitter rivals, but the people to the south of us looked upon us as friends and allies, and were zealous to apply themselves to the task of securing a better understanding in matters of trade and of removing all disabilities. The social features of the meeting were particularly enjoyable, and successful efforts were made to bring the visitors into closer touch with the manufacturers and business men of the United States. This was effected through special excursions to various industrial centres, the results of which were gratifying to all.

The agitation which preceded the war with Spain greatly interfered with the permanent plans of the Exposition, and the outbreak of hostilities compelled a postponement of the Exposition, but not a cessation of preparation for it. Early in the year 1897, the United States Senate, through Dr. Pepper's influence, had passed the Exposition Bill, and in December of the following year the bill passed the House of Representatives. The contribution of the city of Philadelphia, which was included in the loan bill, was delayed by a litigation over the legality of that measure, and was not assured until February, 1899. By March 1 of that year, however, all obstacles were removed. It was decided that further postponement was unadvisable, and the work of erecting the Exposition Buildings was begun. Ground was broken for the main building during the last week in March, and, in less than six months, handsome and commodious structures were erected, three of which were designed for the permanent home of the Museum. On September 14, 1899,

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the Exposition was opened amidst great public enthusiasm, and on October 12 the third annual meeting of the Advisory Board assembled in the name of the International Commercial Congress. This gathering proved a remarkable success. Nearly two hundred foreign delegates, representing thirty-eight governments and one hundred and twelve organizations, participated in the discussions, and there were delegates from the leading chambers of commerce and boards of trade in the United States. So great was the interest which had been aroused in various parts of the world that the Board had increased to one hundred and sixty-eight American and three hundred foreign delegates, or four hundred and sixty-eight in all,—an index of the vast work which the Museum was doing.

Its activity and influence had now become world-wide. All the principal foreign governments were directly interested, and the government of the United States was interested to a degree most gratifying. The Department of State at Washington had acted as the official agent of the Museum and had forwarded all the invitations for the Congress. Every American consul had been instructed to give his official aid in creating an interest in the Exposition and the Congress and to co-operate with the special commissioners of the Museum who were gathering materials for the Exposition in all parts of the world.

The delegates were welcomed by the President of the United States at a special reception given in their honor at Washington. The deliberations of the Congress, which was in session seventeen days, were presided over by many distinguished men, including Honorable Thomas B. Reed, Honorable Cornelius B. Bliss, and Honorable Seth Low. Among the speakers were Ex-Senator George F. Edmunds,

President Eliot, of Harvard, and others of national reputation, among them delegates from foreign countries. More than one hundred papers and addresses of vital interest to the commerce of nations were presented for the consideration of the Congress, and to every speaker were accorded the widest latitude and freedom of speech. Resolutions were adopted upon nine of the most important questions of the day,—such as the immediate construction of the Isthmian Canal, the extension of the parcel-post system, and the establishment of common trade-mark laws. Arrangements were effected to secure frequent meetings between the foreign delegates and visitors and the manufacturers of the United States, especially those who were exhibitors at the Exposition.

The Exposition itself was in many ways remarkable, being entirely original in scope and design, and the first national exposition of American manufactures which are especially suited for export trade. Its design was to bring together in one convenient spot the American manufacturer and the foreign buyer. No better place could have been selected for the purpose than the city of Philadelphia, the metropolis of the principal manufacturing State in the Union. Moreover, the Exposition itself and the Museum, together with the many important manufacturing places located in the city, afforded exceptional opportunities for studying American industries at their best. Here, for example, were the Baldwin Locomotive Works, with the capacity of turning out three locomotives a day; Cramp's ship-yard, the largest in America; and the Pencoyd Iron Works, which built the famous Atbara Bridge in the Soudan. Here, too, were many other noted establishments engaged in the manufacturing of nearly every kind of article known to the American export trade.

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Notwithstanding the fact that the Exposition was held at a time when American manufacturers were busy filling orders consequent upon the revival of business, a large number of instructive exhibits were brought together. There was displayed the latest improved machinery of every type, implements, tools, and labor-saving devices without number. As far as possible every machine was displayed in operation, so as to convey a greater understanding of its uses and advantages. Especially important to the American manufacturers was the department of samples of goods made abroad and sold in foreign markets or prepared in those markets for local consumption. Congress, when it appropriated fifty thousand dollars for the purchase of these samples by the Museum, provided that they should be displayed at the Exposition " for the instruction and benefit of American manufacturers and merchants, thereby laying the foundation of a great system of national education." The Exposition, notwithstanding the obstacles which had to be overcome and the fact that it was the pioneer of its kind, proved a financial success. During the sixty-nine days it remained open it was visited by 1,357,782 persons. Its practical value was recognized not only by Congress, which appropriated in all three hundred and fifty thousand dollars towards it, but also by the President of the United States, who expressed his opinion of the Exposition in his message to the Fifty-sixth Congress.

" The representative character of the exhibits and the wide-spread interest manifested in the special object of the undertaking afforded renewed encouragement to those who look confidently to the steady growth of our enlarged exportation of manufactured goods which has been the most remarkable fact in the economic development of the United States in recent years. A feature of the Exposition

I. INTRODUCTION

The genesis of the Museum Applied Science Center for Archaeology (MASCA) since its inception in 1961 was described in the proposal submitted in 1971 and presumably need not be repeated here. Moreover, that statement also included, in the introduction, definitions of objectives, and the scope of proposed research. In this present request for a continuation of the grant we wish to emphasize results of current research projects, specific new research to be initiated in the coming year, and certain changes in direction which have resulted from archaeological discoveries during the past two years.

MASCA, in collaboration with other research laboratories, has continued to improve the reliability and accuracy of radiocarbon dating through correlation with tree-ring records and has now produced a correction factor table most useful to archaeologists. As the record of tree-ring growth is extended (now to 8,000 years ago) correction for variability in C-14 content in the atmosphere during the past millennia is worked out in MASCA's C-14 laboratory. Hopefully the discovery of more and more ancient bristlecone pines will eventually make it possible to achieve accurate C-14 dates for the past 10,000 years.

Continued research to improve the accuracy and reliability of thermoluminescence dating has been satisfactory. This has also lead to new investigations having to do with the structure and firing temperatures of ancient pottery which not only contributed to improvement in

thermoluminescence method but may lead to new methods of determining the source of clays from which the pottery is made and thus to the reconstruction of trade routes and ancient cultural exchanges.

One of the most dramatic and promising results of work on the TL method this past year has been the discovery that it is possible to date metal slags, crucial in dating the origin and development of metallurgy.

In the field of archaeological search instruments and techniques the most important new development in MASCA this past year is the discovery that ground radar can be used in archaeological prospecting. At least three commercial laboratories are now producing instruments of this kind. Discussions with those companies have resulted in arrangements to begin systematic field testing with engineers in southwestern U.S. this fall. We feel confident that light-weight, simplified, and effective instruments for archaeology can be developed. At present the cesium magnetometer (developed by Varian Associates and MASCA) is still the most sensitive and effective search device. Improved models have been produced for MASCA this year and will be tested during the coming year.

Also in this field of search equipment MASCA has carried out successful experiments in aerial photography, utilizing new films, filters, and other remote sensing devices. But the most promising development is MASCA's arrangement with NASA to carry out the first

experiment in remote sensing for archaeology from a satellite.

Another research project of MASCA which has produced very satisfactory results this year is the preservation of adobe or mud brick structures which have been exposed by archaeological excavation in many regions of the world. Chemical experiments in the laboratory and field testing, in collaboration with the Park Service and the Rohm and Haas Company, have resulted in chemical treatments which are inexpensive and effective. Additional field testing in the Near East, where there are so many mud brick structures to be preserved, will continue next year. This is one of the major problems in archaeological conservation and, after intermittent experiments over many years, a practical solution has been worked out.

The recent archaeological discoveries that now lead to new research for MASCA have taken place in southeastern Asia. There, at Ban Chiang in northeastern Thailand a University Museum expedition, in collaboration with the Thai Department of Fine Arts, is currently excavating a large cemetery containing what appears to be the earliest bronze objects ever discovered (ca. 4500 B.C.). Moreover it has been discovered that copper and tin were available to ancient people in the same locality, a very rare circumstance which may account for the original development of metallurgy in Thailand. There are many ancient slag deposits in the region, which can now be dated (see above). These early

bronzes are high in tin content and demonstrate a sophisticated casting technique. The bronzes and the slag contain other metals, such as lead, which were also utilized by the ancient Thai. Moreover, there is a later iron age at Ban Chiang which may also turn out to be the earliest known work in iron.

The large quantity of metals at Ban Chiang and the slag deposits in Northeast Thailand, as well as the age, are leading MASCA research into analysis and identification of materials in order to learn more about the composition and technique of manufacture by the ancient Thai. This links up with the use and development of new techniques for the analysis of ancient pottery, such as X-ray diffraction studies, and should lead to an understanding of the earliest metallurgy, a fundamental technique in the development of civilized living. Two professors at the University of Pennsylvania, now working with MASCA, Robert Maddin and James Muhly, are specialists in ancient metallurgy and can carry out the interpretation of analysis made by MASCA.

It should be emphasized that the extraordinary discoveries now being made in Thailand are a direct result of MASCA's dating, with thermoluminescence. of a particular kind of pottery, found at Ban Chiang two or three years ago, which was associated in graves with bronze objects. That lead the University Museum to excavate at the site and to the present intensive study of early metallurgy.

II. Explanation of Present and Past Activities of MASCA

A. Radiocarbon Laboratory and Dendrochronology

The foundation of MASCA began in 1951 with the establishment of the radiocarbon dating laboratory, two years after the success of the method was announced by Willard Libby. Since then thousands of C^{14} dates for series of archaeological and anthropological samples have been obtained.

During the past 15 years we have also been dating tree-ring-dated sequoias and bristlecone pines in collaboration with the Laboratory of Tree-Ring Research, University of Arizona. The results of these studies were published both as calibration curves and in tabular form in "Radiocarbon Dates and Reality" (MASCA Newsletter, Vol. 9, No. 1, August 1973). Three thousand copies of this issue have been distributed and the MASCA calibration curve(and tables) are now widely accepted as the best means of correcting C^{14} dates. For example, around 4000 B.C. the discrepancy between C^{14} and dendro-dates is an much as 10 percent. Since publication of the Newsletter, more C^{14} dates for tree-ring-dated bristlecone pines have been obtained. Some of these fill gaps in the calibration curve; others will soon provide a 1000-year extension of the dendro-scale to approximately 8200 B.P. (Before Present).

Henry Michael has conducted extensive field work in the bristlecone pine area of Southeastern California this summer to search for even earlier bristlecone pine remnants that have been washed down the mountainsides and become buried in alluvial fans. For over a month (June-July) he has been sending samples gathered from the canyon floors. From these samples we have been obtaining, almost daily, "quickie" C^{14} dates to determine the "ball park" ages of the bristlecones. So far, none is earlier than 4200 B.P., and indications are that the oldest wood is unlikely

to be found in canyons because they are periodically (that is, every several hundred years) cleaned of most accumulated debris by severe cloud bursts that occur over their drainages. (Beaty, C. B., 1970, Age and estimated rate of accumulation of an alluvial fan, White Mountains, California, U.S.A. American Journal of Science, Vol. 268, pp 50-77). This negative information will aid in the search for earlier tree-ring samples during contemplated field work next year when we will examine the alluvial fans upon and into which the canyon debris, including wood, is deposited. (This work is supported by NSF Grant GA-12572, Division of Earth Sciences).

Peter Kuniholm, whom we instructed in the techniques of dendrochronology, has made significant progress toward the creation of a dendrochronological scale for central Anatolia. His interim report is included here.

DESCRIPTION OF RESEARCH PROJECT IN TURKEY 1973-1974: THE DENDROCHRONOLOGY OF GORDION AND THE ANATOLIAN PLATEAU

by Peter Ian Kuniholm

Using the 806-year sequence of tree-rings provided by the logs in the Midas Mound Tumulus at Gordion as a starting point, I have been trying to build a relative (and eventually, perhaps, an absolute) master tree-ring chronology for the Anatolian Plateau. With the cooperation of the Turkish Department of Antiquities and Museums, I have set up equipment (provided by MASCA at the University Museum, Philadelphia,) for tree-ring analysis in the laboratory of the Museum of Anatolian Cultures in Ankara. Over 110 wood and charcoal samples have been collected at the museum during the past five months, and more are promised.

The Turkish Department of Forestry and its Research Institute have supplied information about modern long-lived trees throughout Anatolia. The oldest sample I have collected is 404 years old, and I have just been informed of the arrival of a 750-year old sample at the forestry station at Saimbeyli. This work with modern trees has interested Prof. Burhan Aytuğ of the Forestry Faculty of Istanbul University who has said he will start assigning dendrochronological theses to his students so that Anatolia can be studied on a regional basis. The Turkish Meteorological Service has also shown interest in this project as its records do not antedate 1926. The climatological information provided by systematic collection and analysis of specimens from all over the plateau should enable the Service to make better projections of past climatic conditions.

The Department of Religious Foundations and its Conservation Section have donated a XVth century timber from a mosque door and have promised more Ottoman and even Selcuk examples from their 1974 restoration season. Old houses in the Ankara citadel are being searched for old timbers. This should assure an extension of the tree-ring chronology well into the first millennium, A.D.

Samples have come from the following archaeological excavations: Gordion (Phrygian and Persian periods); Boğazköy and Eskiyapar (both Phrygian); Adilcevaz (Urartian, from a palace erected by King Rusa II, 685-645 B.C.); Masat (Late Hittite); and Acemhüyük (Kültepe Ib period). Samples from Kültepe have arrived in Ankara and are to be delivered shortly. Pieces from the Phrygian tumuli at Ankara are also promised.

Both Hacettepe University and the Middle East Technical University in Ankara are setting up radiocarbon laboratories. Dr. Mehmet Ergin, the director of the Hacettepe laboratory, has assigned one of his assistants to help me twice a week and to learn as much as he can about dendrochronolgoy. Dr. Ergin hopes to have as many samples as possible tree-ring dated before they undergo radiocarbon analysis. We would like eventually to be able to provide a check on the bristlecone pine corrections to radiocarbon dating.

All this is necessarily a long-term project. We will need many Byzantine and Roman samples if we are ever to achieve an absolute chronology. But the machinery of the collection, analysis, and storage system is in operation, and as the "wood library" builds up and the ring readings are filed (some 16,000 so far), local and regional patterns are becoming more recognizable. I expect to be able to supply evidence of cross-dating between sites within the present academic year.

B. Thermoluminescence and Related Studies.

1. TL Dating and Experiments with Pottery.

During the past 18 months, 100 thermoluminescence (TL) dates have been obtained. Artifacts and sherds have come from sites in Turkey, Africa, Mexico, China, Iran Thailand, Greece, South Pacific Islands, Cyprus, Italy, Egypt, and the U.S.A.

The counting capacity for inherent alphas (an essential part of TL dating) has been increased with the replacement of three non-functional scalers (loaned by Harshaw Chemical Co. for demonstration) by four new ones (purchased from the same company). We now have a total of nine operational counters, which has greatly speeded up the number of samples that can be counted simultaneously. Since the rates of natural alpha emissions are low (normally, 10 to 30 counts per hour), this is the "slowest" step of the total TL measurement. Each sample must be counted for about one week to reduce the statistical uncertainty in the counting rate.

Various minor experiments directed toward the reduction of the size of the sample required for alpha counting have been conducted. So far none has succeeded without loss in counting precision. Experiments are continuing with a new and more uniform type of ZnS screen.

A second TL apparatus has been installed with an especially selected EMI photomultiplier. With this the sensitivity of detection of TL is increased 4-fold. This enables us to detect weaker TL signals. However, with the greater sensitivity, there is a problem in suppressing background noise.

About 20% all thermoluminescent (TL) dates are outside of statistical expectations and a few are extremely deviant, mostly on the too-early side. Therefore, we are continuing to conduct a number of experiments to find out why. The main ones so far fall under two headings:

1. Response of quartz, etc. (The components of clays which produce the TL) to different types of radiation.

Science in Archaeology: A Review

PATRICK E. McGOVERN

The inaugural appearance of yet another "newsletter" of recent archaeological discoveries, reflecting *AJA*'s historic and ongoing commitment to such reviews, is both auspicious and somewhat daunting.[1] Late 20th-century science—here viewed in its more narrow sense as the natural sciences—is now making its share of discoveries in Old World archaeology, a field that some consider a rather esoteric pursuit, divorced from the modern world. A review of this kind might then simply be seen as a long-overdue response to our headlong plunge into a technological present and future. Computers and other "black boxes" are no longer just the province of a few scientific wizards, but are now part of everyone's life, including the archaeologist's, whether we like it or not and whether it produces worthwhile results in our research or not. Since there is no turning back, we all need advice on how best to cope with this revolution and perhaps even come to enjoy it a little more.

Such a review can be as daunting to its author as to its readers. How does one launch an endeavor that has few if any precedents,[2] and which even its practitioners cannot decide among themselves what to call? A roundtable discussion on "Future Directions in Archaeometry,"[3] held in conjunction with the 1981 Archaeometry symposium at Brookhaven National Laboratory, highlighted the fact that "archaeometry" had no precise definition (it has yet to be made an entry in Webster's or the Oxford unabridged dictionary), and that it was too narrowly focused on the physical sciences and connoted too great a concern for precise measurements ("-metry"). Archaeologists might justifiably claim that their measurements, if not so precise, are at least better suited to cultural interpretation and broader issues of why things developed the way they did, how these developments are expressed in the modern world, and whether any predictive value can be attached to such findings.

The phrase "archaeological science" has fared somewhat better,[4] but raises the hackles of both archaeologists (archaeology itself being viewed by many as a social science) and natural scientists, who do not view this as a well-developed discipline. Since "Science and Archaeology" is a similarly infelicitous juxtaposition, I have settled on "Science *in* Archaeology" as the title for this review. This phrase implies that science of whatever variety (social, biological, physical, etc.) has found its way into archaeology, and it is for us to decide whether it is producing worthwhile results.

This review is not intended, however, to cover every scientific approach or application in archaeology, but rather, to present a selected range of viewpoints

[1] Publication of this review has been made possible in part by a generous subvention from the Frederick R. and Margaret B. Matson Fund, established specifically to encourage publication of technological studies in *AJA*. Fred S. Kleiner and Frederick R. Matson are to be especially thanked for first proposing the idea of such a review to me, and then helping to make it a reality by their suggestions, moral support, and, in the case of Fred Matson, contributing an essay of his own on ceramic ecology. Tracey Cullen also provided very thoughtful and practical advice on goals and possible contributors.

For a brief history of archaeological newsletters in *AJA*, see F.S. Kleiner, "Archaeology in Asia Minor/Anatolia, 1955–1993," *AJA* 98 (1994) 1–3.

[2] In the United States, the Society for Archaeological Sciences publishes the *SAS Bulletin*, which is a very useful "newsletter" that provides up-to-date information on advances in the field, meetings, publications, and funding opportunities. A series of textbooks on the archaeological sciences is also currently being prepared by members of this society in collaboration with Plenum Press, New York. Another newsletter that has kept archaeologists abreast of some of the latest developments is the "Archaeometric Clearinghouse" in *JFA*. C.W. Beck, who assiduously saw this review through 26 installments, retired last year, and the editorial reins have now been passed to J. Henderson of Sheffield University. More specialized newsletters are also published on a regular basis—e.g., *La Tinaja*, which deals with archaeoceramics and is edited by J.E. Corbin (Box 13047, SFA Station, Nacogdoches, Texas 75962-3047), and the series of reviews on archaeometallurgy in the *Journal of Metals*, edited by V.C. Pigott (MASCA, University Museum, University of Pennsylvania, Philadelphia, Pennsylvania 19104). Rather than duplicate what can already be found in these and other more eclectic newsletters, this overview attempts to take stock of the "field" and develop guidelines for effective research and discussion among archaeologists and natural scientists.

[3] J.S. Olin ed., *Future Directions in Archaeometry: A Round Table* (Washington, D.C. 1982).

[4] L. van Zeist, "Archaeometry: The Perspective of an Administrator," in R.L. Bishop and F.W. Lange eds., *The Ceramic Legacy of Anna O. Shepard* (Niwot, Colo. 1991) 346–57.

and examples of how natural science functions within an archaeological framework. Future reviews, assuming that this one is well received, will expand into areas not covered here and, it is hoped, will lead to more fruitful theoretical perspectives on how best to integrate science with archaeology.

The terminological debate is largely a symptom of how poorly defined and amorphous the "field" is at present, as well as disillusionment with methods or approaches that promised more than they delivered. If an academic discipline constitutes an autonomous body of knowledge, with recognized practitioners, places where research is carried out, and appropriate journals, publications, professional groups, and conferences to disseminate the findings,[5] then the "archaeological sciences" are still very poorly developed. National, museum, and private laboratories[6] do exist in the United States, Europe, and elsewhere, providing a context for specific applications of science to archaeology, but these facilities primarily play a support role, either focusing their efforts on individual collections and in-house projects or providing a commercial service to archaeologists (especially dating and geophysical prospecting). Academic programs, which might serve to foster research and develop a tradition of scholarship, are virtually nonexistent.[7] Public and private funding is difficult to obtain, because such research is too "interdisciplinary"– it does not fit squarely into any established discipline. With the all-too-common cutbacks in budgets generally, science in archaeology will probably continue, for the foreseeable future, to be carried out by widely scattered individuals and the occasional research group, approaching the subject from various scientific or archaeological perspectives. Science in archaeology truly suffers from C.P. Snow's "two culture" split personality.[8] It may seem exciting to explore a borderline discipline (where serendipitous discoveries so often occur[9]) and become a polyglot interpreter of sorts,[10] yet the would-be practitioner must be prepared to be misunderstood and certainly underfunded.

To be fair, the sheer dimensions of possible interactions between archaeology and the natural sciences, ranging from the subatomic to the astrophysical level, preclude any simple definitions and hence a more systematic approach. Some may choose to divide up the field by physicochemical techniques (whether neutron activation analysis, mass spectrometry, or optical microscopy),[11] others may opt for a materials science approach (ceramics, metallurgy, etc.),[12] while still others will argue for a general problem approach (such as establishing trade networks, reconstructing palaeodiets, or elucidating

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[5] See F.R. Matson, "Archaeological Ceramics and the Physical Sciences: Problem Definitions and Results," in J.S. Olin and A.D. Franklin eds., *Archaeological Ceramics* (Washington, D.C. 1982) 19–28; U. Franklin, "The Science of Ancient Materials: A New Scholarly Field," *Canadian Mining and Metallurgy Bulletin* 70 (1977) 207–10.

[6] Olin (supra n. 3) 109–45 (section on the "Roles of Museum, University, Government, and Industrial Laboratories") and van Zeist (supra n. 4). A recent British Museum publication, S. Bowman ed., *Science and the Past* (Toronto 1991), provides an excellent overview of interdisciplinary research in the Department of Scientific Research of the British Museum that will be readily comprehensible to the nonspecialist.

[7] New and Old World archaeology, incorporating natural scientific training to some extent, are taught in the same academic department (Archaeology) at Boston University. Several programs are also attached to materials science and/or anthropology departments in the United States (e.g., the Massachusetts Institute of Technology and the University of Arizona) and Canada (University of Toronto). In England and Germany, separate departments of archaeological sciences (e.g., the University of Bradford and the Institute of Archaeology at the University of London) exist or have integrated natural scientific studies effectively into their archaeological curricula. Conservation programs (e.g., at the Institute of Fine Arts in New York or the Institute of Archaeology at the University of London), although having more pragmatic goals, clearly demonstrate the desirability and need of coupling archaeology and natural sciences. See J. Riederer ("Teaching Archaeometry as a Basis of Archaeometric Research") and S.E. Warren ("The Education of the Archaeological Scientist") in Olin (supra n. 3) 34–35 and 36–38, respectively, and the discussion session 34–46; also see J.A. Sabloff, "Toward a Future Archaeological Ceramic Science: Brief Observations from a Conference," in Bishop and Lange (supra n. 4) 394–99.

[8] C.P. Snow, *The Two Cultures and the Scientific Revolution* (New York 1963).

[9] R.M. Roberts, *Serendipity: Accidental Discoveries in Science* (New York 1989).

[10] C.S. Smith, "Measurement and History," in Olin (supra n. 3) 49–51.

[11] Textbooks of archaeometry, exemplified by M.S. Tite's *Methods of Physical Examination in Archaeology* (London 1972), have generally followed this format.

[12] This approach has much to commend it, since the materials sciences are now a recognized academic discipline involving interdisciplinary scientific research. The detailed study of technological features of artifacts or art objects, as well as the elucidation of corrosion and other processes of physical and chemical change, have obvious applications in museum curatorship, art history, and archaeology generally. Collaboration with and financial backing from private industries is a natural extension of this academic liaison.

cognitive processes of ancient humans).[13] Each approach has its advantages and disadvantages, and may seem relatively more interesting or boring to the archaeologist or natural scientist,[14] but all share the premise that information made available only by the natural sciences can be used to shed light on issues ranging from the most fundamental—for example, dating an archaeological site or artifact—to the most ambitious and potentially important, viz., the origins and development of humans and their cultures.

It is not difficult to understand why science should play an important role in archaeology. The general principles and empirical procedures of stratigraphic excavation and record-keeping, as well as site survey and landscape archaeology, themselves embody the empirical observation and systematization that characterize science. Unlike chemistry and physics (the "hard sciences"), experiments in archaeology cannot be repeated, but, like geology or astronomy, archaeology is concerned with evidence of past events (during the relatively short span of earth history over the past several million years) and the interpretation of that evidence within a more general theoretical context. In the historical natural sciences, a limited range of materials is subjected to a battery of analyses (material, imaging, and statistical), and interpretations are based on general scientific "laws" (uniformitarianism, the structure and mutation rates of DNA strands, the speed of light, and so forth). Even with their sophisticated tools (like the Hubble space telescope), there is room for disagreement on how the data should be interpreted. As just one example, not all scientists agree that the dinosaurs were warm-blooded, social creatures, or that they became extinct when an asteroid collided with the earth.

Archaeologists also aspire to generalized and detailed reconstructions in time and space, as well as establishing cause and effect relationships, based on an analysis of its restricted data base. Unfortunately, because of the disciplinary schizophrenia already mentioned, most archaeologists are not trained in how to extract natural scientific information from their sites and the artifacts that they recover. Lacking a basic knowledge of the natural sciences, archaeologists are at a disadvantage in properly recovering and interpreting materials from sites that have certainly been altered by geological and biological processes and of which now mostly inorganic materials remain. Some archaeologists, recognizing the deficiency in their training, have the good sense to enlist the help of natural scientists in a multidisciplinary effort, which is the hallmark of most modern scientific projects. Unless the natural scientist's role is to be no more than "window-dressing," however, there has to be a very serious attempt by all involved, archaeologist and natural scientist alike, to articulate the goals of the project in their respective "languages" and develop an effective research design for answering some significant cultural questions.[15] Placing specialist studies with little if any relationship to the archaeological interpretations at the end of an excavation report illustrates how *not* to do interdisciplinary research. Equally reprehensible is a scientific study of unprovenienced, possibly fake, archaeological material parading masses of data that may have been generated by the most sophisticated analytical tools available but which are archaeologically meaningless.[16]

The communication gap between natural scientists and archaeologists is exacerbated by the human dimension, which cannot be easily factored into an

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[13] Such studies are interdisciplinary almost by definition. For example, a recent conference on "The Origins and Ancient History of Wine" (in press, under the same title, and edited by P.E. McGovern, S.J. Fleming, and S.H. Katz) brought together specialists in palaeoethnobotany, archaeology, genetics, enology, art, food science, chemistry, textual analysis, and history. Besides reviewing and debating the available evidence for viticulture and viniculture, participants were encouraged to look at this beverage, which played an important role in the diet, economy, social structure, and religion of ancient societies, from a variety of perspectives and develop innovative approaches to answer culturally significant questions. As just one example, many centuries of experimentation in plant domestication and crossbreeding, wine making itself, and in pottery technology (to produce relatively airtight, stoppered vessels of dense fabrics) were presumably required to reach the level of expertise that is evident by ca. 3000 B.C. in Egypt and Mesopotamia—but where is the evidence for these developments, and how is it to be recovered from excavations and scientifically verified? By attempting to tailor our survey, excavation, and analytical strategies to specific research objectives, the advantages of collaborative research, despite the specialization and fragmentation of modern knowledge, will become apparent.

[14] F. Widemann, "Why Is Archaeometry So Boring for Archaeologists?" in Olin (supra n. 3) 29–36.

[15] Supra n. 13. Also see S.P. De Atley and R.L. Bishop, "Toward an Integrated Interface for Archaeology and Archaeometry," and De Atley, "Potter's Craft or Analyst's Tool: A Century of Ceramic Technology Studies in the American Southwest," in Bishop and Lange (supra n. 4) 205–23 and 358–80, respectively.

[16] J.A. Moore and A.S. Keene eds., *Archaeological Hammers and Theories* (New York 1983).

interpretative schema and which makes archaeology a very "soft" science. Archaeological remains often appear to be an extension of the natural world, simply needing to be subjected to thorough physical and chemical investigation for their significance to be elucidated. In some instances, this may be true. The microstructure of a ceramic or metallurgical artifact may reveal how it was made, and by the cautious use of ethnographic analogy, even some facets of the organization of the industry.[17] Certainly, the radiocarbon reservoir in the oceans and atmosphere was little affected by human intervention before the industrial revolution, so that one can have confidence in dates based on this technique (assuming adequate tree-ring calibration, elimination of contaminants, and statistical evaluation). On the other hand, what may appear to be the result of natural processes (e.g., pollen rain, a soil lens, or patination on glass) might also have been affected by human activity, and cannot be explained solely by physicochemical factors.

Archaeologists understandably seek cultural interpretations that even the natural scientist should be willing to admit are at a higher level of abstraction[18] than, for example, the reconstruction of an ancient regional environment or the significance of some group of artifacts for the history of science. Anthropologists, as social scientists, may seek to make generalized statements about social and economic structures, religious ideology, or cross-cultural interactions that are derived from their archaeological data bases.[19] Historians may attempt to interrelate archaeological findings to information—whether psychological, social, or environmental—gleaned from contemporaneous and noncontemporaneous documents that have been subjected to critical study.[20] Art historians in evaluating specific objects may emphasize aesthetic canons of judgment. Each kind of interpretation has its place, with the proviso that they should be inferred from as careful and thorough an appraisal of the field and laboratory data as possible.

Lacking most of the material evidence that once existed, especially the organics that comprised humans themselves, their personal belongings and buildings, food, etc.,[21] archaeological interpretations are *per force* extremely weak. A deficiency of data, however, should not be taken as an excuse for fuzzy thinking. The consequences of an interpretation based on the available data should be deduced; if borne out, the hypothesis gains in credibility.[22] Tests that demand a tangible outcome, such as a certain microstructure in a metal or a specific artifact distribution, can provide extremely powerful support for a hypothesis, because archaeological evidence is unintentional and contemporaneous (with the rare exception, e.g., conspicuous consumption in a burial). Thus, it was not "planted" to achieve some ulterior purpose in the distant future nor to rewrite history after the fact.

Archaeological interpretations will never achieve the same level of confidence as those in the natural sciences—there are far too many interacting and unknowable factors to assess—but by making testing procedures explicit, archaeologists and natural scientists can share a common ground and language of scientific inquiry. Fuzzy archaeological thinking, of course, may continue to thrive, because its effects are not as immediately obvious as in the natural sciences where, for example, bridges fall and rockets explode if a theory or its application is incorrect. Moreover, for some people, rhetoric and politically correct paradigms, serving to preserve disciplinary power structures and financial support, are more persuasive than probabilistic statements. Well-thought-out and tested ideas, which have profound implications for how we define ourselves and our cultures, often are lost in the process.

Clearly, a middle way needs to be found—what in the parlance of anthropological archaeology is called middle-range research[23]—to bridge the practical and theoretical divide between natural scientists and archaeologists. The essays that follow are

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[17] W.D. Kingery, "Possible Inferences from Ceramic Artifacts," in Olin and Franklin (supra n. 5) 37–45.

[18] Smith (supra n. 10).

[19] E.g., supra ns. 13 and 15; also see P.E. McGovern, "Ceramics and Craft Interaction: A Theoretical Framework," in P.E. McGovern ed., *Cross-Craft and Cross-Cultural Interactions in Ceramics* (Ceramics and Civilization 4, Westerville, Ohio 1989) 1–11.

[20] E.g., M. Bloch, *The Historian's Craft* (New York 1953); and H. Meyerhoff ed., *The Philosophy of History in Our Time* (Garden City 1959).

[21] W.R. Biers and P.E. McGovern eds., *Organic Contents of Ancient Vessels: Materials Analysis and Archaeological Investigation* (MASCA Research Papers in Science and Archaeology 7, Philadelphia 1990) passim.

[22] Kingery (supra n. 17).

[23] J.A. Sabloff, L.R. Binford, and P.A. McAnany, "Understanding the Archaeological Record," *Antiquity* 61 (1987) 203–209.

offered in that spirit. For the first installment of this newsletter, contributors were asked to summarize for the educated layman past accomplishments, as well as failings that can be equally revealing, in their fields. By focusing on examples of past or recent interdisciplinary successes, together with practical advice on how to collect samples for analysis, apply correction factors, and so forth, it is hoped that the reader will be able to extrapolate and begin to apply similar approaches to his/her own research.

To reiterate, this newsletter is necessarily selective in its coverage of a vast, poorly developed "field," and many gaps still remain. If greater attention than usual is paid to the biological, chemical, and earth sciences, that is because less is known about these interdisciplinary endeavors that are generally at the "cutting edge" of current research. Each contributor, by standing at the interface of two or more disciplines, epitomizes, as it were, how much archaeology has to gain by emphasizing its essential, interdisciplinary character.

The following essays take the reader from locating and situating sites within an environmental setting (Remote Sensing, Aerial Photography, Geophysical Prospecting, Archaeobotany, Palynology, and Archaeozoology) to dating them (Dendrochronology, Radiocarbon Dating Calibration, Accelerator Radiocarbon Dating), analyzing a range of materials recovered from them (Ceramic Ecology, Ceramic Petrography, Ceramic Petrology and Petrography in the Aegean, Vitreous Materials, Xeroradiographic Imaging, Amber, Physical Anthropology, Ancient Immunochemistry, and Palaeogenetics), and, finally, preserving the finds for future scientists and humanity in general (Archaeological Conservation).

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Remote Sensing

THOMAS L. SEVER

New windows on the past are being opened through the use of remote sensing technology.[24] Remote sensing is based upon the fact that all materials emit energy along the electromagnetic spectrum. Archaeologically relevant information, most of which cannot be seen with the naked eye, can be recorded by detectors along this spectrum and processed for view on a computer. Sensors are mounted on satellites, space shuttles, airplanes, and balloons, dragged on the ground, or simply manipulated by hand.

Beginning at the turn of the century, archaeology was one of the first disciplines to employ remote sensing. Using black-and-white aerial photography, archaeologists recorded ancient features that could not be seen or understood from ground level. During World War I, for example, British archaeologists described aerial photographic "features of long-obliterated structures in the terrain, soil formations, and vegetative cover . . . that are either invisible or easily overlooked in surface reconnaissance."[25] This capability subsequently led to the discoveries of ancient Roman villas and roadways in Europe, sites in the Middle East, and earthworks in the Mississippi River valley.

SATELLITE IMAGERY

The launch of the first land satellite (Landsat) in 1972 ushered in a new era in remote sensing. Computers were now required to handle the digital data format and convert the information into photograph-like products. The multispectral capability of satellite imagery enabled several regions of the electromagnetic spectrum to be recorded simultaneously. Since archaeological features show up through soil variations, moisture differences, plant stress, etc., multispectral information can be used to detect subtle features. No part of the spectrum is necessarily

[24] C.A. Behrens and T. Sever, *Applications of Space-Age Technology in Anthropology* (Bay St. Louis, Miss. 1991); T.M. Lillesand and R. Keifer, *Remote Sensing and Image Interpretation* (New York 1987).

[25] T.S. Schorr, "Aerial Ethnography in Regional Studies: A Reconnaissance of Adaptive Change in the Cauca Valley of Colombia," in E.Z. Vogt ed., *Aerial Photography in Anthropological Field Research* (Cambridge, Mass. 1974) 163.

any better than any other part for detecting archaeological features, since the material comprising the feature, atmospheric conditions, and the time of the year result in different energy outputs.

Although the first Landsat satellites recorded information at only 80-m resolution, current foreign and domestic satellite systems can record information ranging from 30-m down to 1-m resolutions (e.g., using French SPOT satellite imagery).[26] New advances in airborne remote sensing instrumentation allow multispectral acquisition at resolutions of one foot or less. Remote sensing analysis used to require huge mainframe computers and expensive software; today, data can be processed on a personal computer using inexpensive and readily understandable software.

As one example of the new high-tech view from space, the possible remains of the ancient city of Ubar were recently located through faint traces of caravan trails. Researchers could see various parts of these trails on Landsat, SPOT satellite, and shuttle imaging radar data. By excavating at a spot where these trails converged, archaeologists uncovered an eight-sided fortress surrounded by smaller sites used by caravans.[27]

Satellite data have been used in western Greece to locate a variety of physical features, including stone quarries, coal mines, oak and silver fir forests, and clay beds used for pottery-making. This information provided greater insight into ancient fortifications, hydraulic systems, and settlement patterns.[28] On the other side of the globe, satellite data are currently revealing unmapped Mayan pyramids and roadways in the Peten region of northern Guatemala.[29]

Remote-sensing instruments can be flown in Lear jets or Cessna aircraft to provide greater resolution. Aircraft data at 5-m resolution were able to detect ancient Anasazi roads in Chaco Canyon, New Mexico.[30] The same six-band thermal instrument was also flown at 5-m resolution over the jungles of northern Costa Rica to detect the oldest confirmed footpaths.[31] Despite the environmental differences between New Mexico and Costa Rica, both the desert roads and jungle paths, invisible to the human eye from the air and ground level, were detected due to minute differences in heat retention.

GLOBAL POSITIONING SYSTEM (GPS)

GPS technology is revolutionizing archaeology and enhancing the effectiveness of remote sensing research because it enables ground positions to be determined to centimeter accuracy.[32] The GPS system consists of 24 satellites orbiting 11,000 miles above the earth. GPS signals can be received directly with a hand-held receiver. Besides being extremely useful in remote, poorly mapped regions, GPS locates archaeological features that have been detected in remote-sensing imagery but are invisible on the ground.

CONCLUSION

Although archaeologists pioneered the use of remote sensing, most mainstream archaeologists of the late 1970s and '80s were reluctant to invest in the technology. By then remote sensing had evolved into an expensive enterprise, requiring knowledge of optical physics, advanced computer analysis, and multivariate statistics—disciplines generally outside the purview and funding of archaeological research programs. Today, however, the technology is becoming increasingly affordable and understandable. It is a nondestructive technology that protects our human legacy by allowing archaeologists to map entire regions and prioritize areas for excavation while simultaneously preserving cultural resources for future research.

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[26] Lillesand and Keifer (supra n. 24); B. Richason ed., *Remote Sensing of the Environment* (Dubuque 1983).

[27] W.F. Allman, "Finding Lost Worlds," *U.S. News and World Report* (13 September 1993).

[28] F.A. Cooper, M.E. Bauer, and B.C. Cullen, "Satellite Spectral Data and Archaeological Reconnaissance in Western Greece," in Behrens and Sever (supra n. 24) 63–79.

[29] F. Miller, T. Sever, and D. Lee, "Applications of Ecological Concepts and Remote Sensing Technologies in Archaeological Site Reconnaissance," in Behrens and Sever (supra n. 24) 121–36.

[30] T. Sever, *Tracing Prehistoric Human Impact upon the Environment* (Ann Arbor 1990) 116–258.

[31] P. Sheets and T. Sever, "Prehistoric Footpaths in Costa Rica: Transportation and Communication in a Tropical Rainforest," in C.D. Trombold ed., *Ancient Road Networks and Settlement Hierarchies in the New World* (Cambridge 1991) 53–65.

[32] D. Wells, *Guide to GPS Positioning* (Fredericton, New Brunswick 1987); A. Leick, *GPS Satellite Surveying* (New York 1990); N. Ackroyd and R. Lorimer, *Global Navigation: A GPS User's Guide* (London 1990).

Low-Altitude Photography

J. WILSON MYERS AND ELEANOR EMLEN MYERS

BEGINNINGS

The first systematic use of a tethered photographic balloon to record an ongoing excavation was made in 1931 at Megiddo, site of biblical Armageddon, by Philip Guy (fig. 1).[33] Operating out of the Oriental Institute at the University of Chicago, field director Guy used a single-shot 8 × 10″ cut-film camera and a spherical hydrogen balloon to assemble detailed mosaics at successive stratigraphic levels. This bird's-eye view, he reported, allowed him to see continuities and patterns that went unobserved on the ground. Guy used these vertical photographs, which included points of his surveyed grid, to eliminate much measuring on the ground and make lighter work of the drawings. But his single-shot camera had to be pulled down and reloaded for each new exposure—a tiring process that used up the short precious time in the morning when the angle of the sun was right and the air quiet. In fact, a Megiddo colleague later told us that the balloon did not handle well in the wind, and Guy quietly abandoned the method as impractical at the season's end when a sudden gust crashed his camera.

Fig. 1. The pioneer photographic balloon used by P.L.O. Guy at the Megiddo excavation in 1931. It lifted a single-shot view camera whose shutter was released electrically by a wire cable running to the right-hand reel and connected with a box of batteries below. (Courtesy Oriental Institute, University of Chicago)

We learned firsthand about balloon site recording in Greece in 1973 while working with Michael Jameson at his excavation of the underwater sanctuary of Apollo at Halieis, where Julian Whittlesey brought his spherical balloon.[34] Invited to help him, we became interested ourselves in the process, seeing that much time was saved with a modern radio-controlled motor-driven camera. Our own 20 years of aerial archaeology in the Mediterranean started then and has since taken us to over 150 sites and area surveys in Italy, Sicily, mainland Greece, Crete, Yugoslavia, Israel, Turkey, and most recently Jordan. Though much of the coverage has been scattered, carried out at the request of individual excavators, it has also been possible to fund work on a regional basis, producing a site atlas for reference and comparative study.[35]

APPLICATIONS AND ADVANTAGES

For exploration, salvage work, comparing successive levels of excavation, and preservation of visual information for future study, vertical photographs provide an expeditious unique perspective, constituting a permanent record. In the raking light of early morning, even the slightest contours, as traced by their highlights and shadows, stand out in high relief. One is able to spot relationships not easily seen at ground level. Over a level site, vertical aerial photographs are the dimensional equivalent of a drawn plan.

The obvious advantage of a balloon or blimp over a plane is that it can come low to capture details, such as a single house or a mosaic floor. Helicopters can fly lower than planes, but the powerful downwash of their rotors can damage fragile remains and disturb the water over submerged sites.

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[33] P.L.O. Guy, "Balloon Photography and Archaeological Excavation," *Antiquity* 6 (1932) 148–55.

[34] See Whittlesey's aerial photograph in M.H. Jameson, "The Excavation of a Drowned Greek Temple," *Scientific American* 231:4 (1974) 110–19.

[35] J.W. Myers, E.E. Myers, and G. Cadogan eds., *The Aerial Atlas of Ancient Crete* (Berkeley 1992).

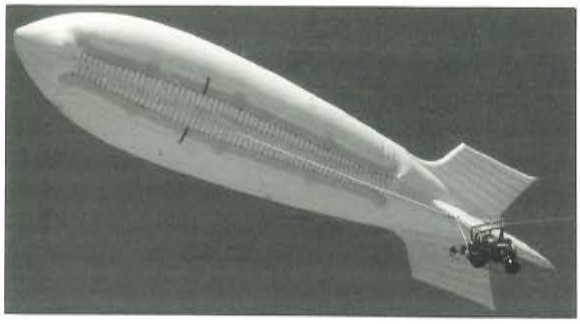

Fig. 2. A modern 10-m pressurized blimp. Twin motor-driven cameras are held vertically in a precision gimbal and operated by FM radio control.

EQUIPMENT AND METHODS

Through much experimenting, we have gradually settled on methods and equipment that are most suitable. Problems with a spherical balloon had suggested that a blimp might be easier to handle in the wind. Working with design engineers at Raven Industries of Sioux Falls, South Dakota, we had a blimp made that meets our requirements (fig. 2). It is 10 m long, with four fins that keep its streamlined shape headed into a breeze, offering less drag area than a spherical counterpart. Inflated with 35 m^3 of hydrogen or helium, the blimp lifts 8 lb of cameras to 800 m—the altitude from which a square kilometer can be photographed. Above 800 m, air photographs from a plane would be more efficient.

Equipped with an elastic dilation panel, the blimp expands without bursting as it rises into thinner air, and contracts again, holding its aerodynamic shape, when lowered. A still larger blimp, though more stable in the wind, would require heavy winching equipment and restrict movement. The hand-held system allows us to move quickly through shifting positions at a large site, while some remote sites can only be reached on foot.

Twin cameras allow us to make both black-and-white negatives and colored slides at the same instant. The medium format Hasselblad ELM/500 produces 55 mm negatives, best for journal publication (fig. 3), while the 35 mm camera, a Canon AE-1 or a Nikon 2020, makes slides. The cameras are mounted in a precision gimbal—like that which holds the compass level on a heeling ship—thus stabilizing them vertically and eliminating the distortions in scale that appear in oblique views. The tethers of ⅛″ braided polyester cord are carried on light backpack reels designed for taking up the slack as crew members haul down the balloon.

The altitude at which the cameras are positioned is determined by the dimensions of the target on the ground. Given the focal length of the lens and size of the film, the proper altitude is derived from a ratio (fig. 4): focal length is to film size as altitude is to the size of target. For shots below 200 m, two tethers are generally used, angled down from opposite sides of the gimbal to keep both cords and backpacks just outside the photograph. Thus, the frame of the photograph is closely fitted to the shape of the target. Simple calculations made on a working plan are used to decide exactly where each reel must be positioned and how much tether line let out. Above 200 m, two tethers would be difficult to control and might tangle in a tricky breeze. With a single tether, the altitude of the camera is judged by patches of colored yarn tied to the tether line at calibrated intervals. For the higher shots, the necessary framing is done by cropping in the darkroom. With wide-angle lenses, 60 mm for the Hasselblad and 28 mm for the smaller camera, the focusing distance can safely be set on infinity.

Accessory equipment has also proven useful in the field: a surveyor's tape and prismatic compass for making a working plan of unrecorded sites; a small turbine anemometer to help us decide whether a slight breeze is increasing and might cancel a planned inflation; heavy canvas ground cloths on which to unroll and inflate the easily punctured balloon fabric; a set of walkie-talkie radios, allowing crew members at widely separated tether positions to communicate with each other and with the operator controlling the camera; a portable light table

Fig. 3. A Hasselblad medium-format vertical photograph of the little theater in the Sanctuary of Asklepios at Messene, Greece.

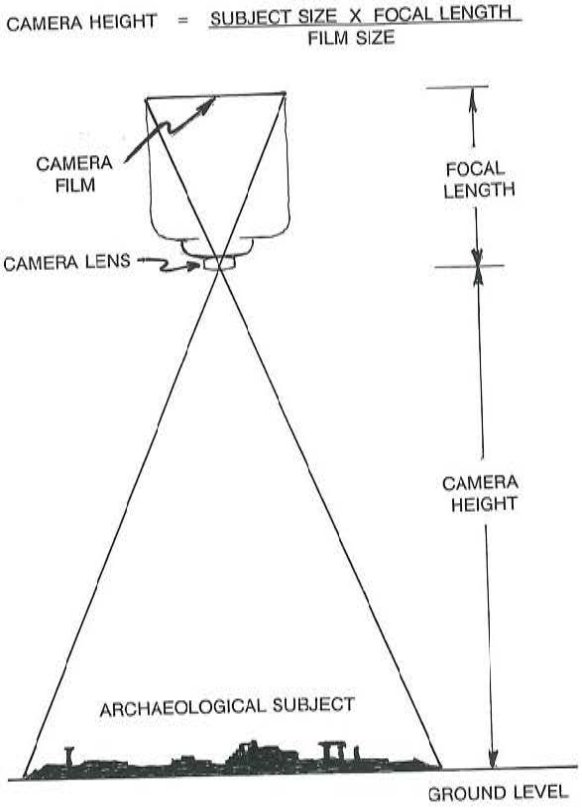

Fig. 4. With vertical photography, the size of the subject on the ground determines the proper height of the camera. One need only know the focal length of the camera lens and the size of the film.

for studying the day's negatives with magnifiers; and, where remote sites are not easily located on maps, a miniature global positioning device to measure and record latitude, longitude, and altitude.

CAUTIONARY NOTES AND PROBLEMS

We described above Guy's problems with the wind at Megiddo. Even with an aerodynamic blimp, one must be careful. Because it may take 20 minutes to haul down the equipment from 800 m, it is important not to have the blimp caught aloft in a rising wind. At a certain wind velocity, even a blimp will begin to veer off to the side, its fins less and less able to head into the wind, and finally broach, turning broadside to the wind and heading straight for the ground, all lift lost to the weight of the cameras and the horizontal force of drag. Recovery here is possible only if the ground crew can run toward a sinking blimp fast enough to slacken tether and allow it to rise again. Even then, the balloon can be pulled down gradually only when the wind lulls a bit. It is best to avoid these panic situations by hauling down as soon as one feels an increasing pull on the tether.

Delays in the photographic schedule are best avoided by learning early what permissions a country requires from civil air or military authorities or what advance notice to authorities would be prudent and courteous. Sources of hydrogen or helium should be located and arrangements made early for prompt commercial delivery.

OTHER BALLOON SYSTEMS

We have regularly responded to requests for information from others who would like to start their own balloon systems and increasingly hear of successful recording. Good examples of balloon photography appear regularly in *AJA*.[36] A very simple and inexpensive 35 mm system, with a servo-motor to incline the camera, but limited in altitude to 100 m, is described by Dieter Noli.[37] G.D. Summers reports flights of a tethered blimp as high as 850 m to record a site in Turkey.[38] Andrew Heafitz has developed an ingenious radio-controlled servo-system that can incline and rotate the balloon camera in any direction. A video camera, mounted together with a still-camera that monitors the coverage, transmits the image to the ground, allowing the operator to see exactly what the still-camera will record.[39]

There is little doubt that archaeologists of the future will use increasingly sophisticated methods to record and examine sites in minute detail at low altitude. The whole range of remote-sensing equipment, operating in the infrared to radar ranges and now used for sophisticated regional surveys by plane or satellite, may one day be miniaturized for low-altitude suspension over archaeological sites. Much subsurface investigation might then be conducted without the traditional digging that has been described with cautionary irony as the systematic destruction of evidence.

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[36] See *AJA* 92 (1988) 124; 93 (1989) 130; 95 (1991) 22; 96 (1992) 140–45.

[37] D. Noli, "Low Altitude Aerial Photography from a Tethered Balloon," *JFA* 6 (1985) 497–501.

[38] G.D. Summers, "An Aerial Survey of Çevre Kale, Yaraşlı," *AnatSt* 42 (1992) 180–81.

[39] A. Heafitz, Appendix 3: "Balloon Photography," in J.E. Coleman, "Excavations at Halai, 1990–1991," *Hesperia* 61 (1992) 287–88.

Geophysical Prospecting

BRUCE BEVAN

A successful geophysical survey will allow a prediction of the location of sites or the location of features within sites. This should help to minimize the cost of excavation and enable a wide variety of features to be examined.

While remote sensing usually does not allow the detection of a feature deeper than about 1 m, geophysical exploration can detect a feature at any depth, although its maximum dimension must typically exceed its depth.

THE INSTRUMENTS AND THEIR LIMITATIONS

One of the first instruments to be applied to archaeological geophysics was the magnetometer.[40] A magnetometer measures slight changes in the earth's magnetic field; a commonly used instrument has a sensor mounted on a vertical staff and connected with a wire to a small console where the measurements are displayed. Point-by-point measurements, spaced 1–2 m apart, create a magnetic map of the area of interest. The magnetometer is excellent for locating iron artifacts as well as fired earth in the form of brick, rooftiles, kilns, or furnaces. Surveys with a magnetometer are generally more rapid than those with other geophysical instruments, and are also more easily done in brushy, wooded, or rocky areas. They are less suitable for urban areas and regions with igneous rock.

Resistivity surveys are relatively easy to carry out. Wires connect a small resistivity meter to four electrodes driven into the earth; the meter indicates how readily electrical current flows through the soil.[41] Resistivity surveys are ideal for locating concentrations of stone in the soil (e.g., walls) and also for mapping filled-in pits and trenches. Because of the electrodes and wires, resistivity surveys are difficult to carry out in rocky or brushy areas.

Conductivity surveys are performed with instruments that operate somewhat like very sensitive metal detectors.[42] They will locate the same types of features that a resistivity survey will, but conductivity surveys are faster since no contact is made with the ground. Conductivity surveys are difficult to carry out near cities and in areas with metal trash in the soil, but wooded or rocky areas do not cause major difficulties.

Ground-penetrating radar is the most elaborate of the commonly used geophysical instruments, and will detect a wider variety of features than the other instruments.[43] Radar generates an approximate cross-sectional image of the earth; while these images are similar to sonar records, the radar emits a radio rather than a sound pulse. Radar is generally not suitable for sites where the soil is saline or quite clayey; it also cannot be used if there are many large boulders or much brush on the surface.

For special applications, seismic and gravity instruments can also be employed. Seismic equipment measures the speed of sound in the soil, while a gravity meter measures the density of materials that are underground. Surveys with these two instruments, however, are quite slow.

CAPABILITIES FOR LOCATING DIFFERENT FEATURES

The ancient ground surface may be buried below a layer of modern soil. The depth of this deposit can be estimated with a resistivity, ground-penetrating radar, or seismic survey. The entrances to rock shelters, caves, mines, and quarries may be hidden by soil, and can sometimes be detected with any of the geophysical instruments. Tunnels or chambers that are air-filled cavities can be readily detected with ground-penetrating radar and, in special circumstances, with a gravity survey.

The former channels of rivers, buried roads, or filled-in ditches can be mapped with any of these geophysical instruments. Because of the large size of these features, aerial or satellite reconnaissance may be most suitable.

Tells and tumuli often have stratigraphy that is too complex for geophysical surveys to resolve. While structures in the upper few meters can be mapped as at any other site, small and deep features cannot be detected. General mound stratigraphy, however,

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[40] A. Clark, *Seeing beneath the Soil* (London 1990).

[41] G. Shapiro, "A Soil Resistivity Survey of 16th-Century Puerto Real, Haiti," *JFA* 11 (1984) 101–10.

[42] W.A. Martin, J.E. Bruseth, and R.J. Huggins, "Assessing Feature Function and Spatial Patterning of Artifacts with Geophysical Remote-Sensing Data," *AmerAnt* 56 (1991) 701–20.

[43] R.A. Batey, "Subsurface Interface Radar at Sepphoris, Israel, 1985," *JFA* 14 (1987) 1–80.

Fig. 5. Elizabeth Ralph recording cesium magnetometer measurements at Malkata, Egypt, with an Egyptian colleague and assistants carrying the cesium magnetometer sensor and readout

particularly on the sides of the mound, can be approximated, and resistivity surveys are generally the most appropriate technique. The stratigraphy of burial mounds is usually simpler and, if the burial chamber is at least as large as its depth underground, it might be detected.

Building remnants can be detected under ground or under water. If a buried wall is surrounded by rubble from the wall, it will generally be impossible to isolate the intact wall with geophysical exploration. Brick walls or concentrations of rooftiles will usually be easier to delineate than stone walls. Mudbrick or adobe walls may be detectable in sandy soil and limestone walls may be detectable in clayey soil.

If kilns, furnaces, or iron objects are sought, a magnetic survey is recommended. In some cases, concentrations of pottery or other fired ceramic materials can be located.

Isolated artifacts will generally be difficult to locate with any geophysical survey. A large object such as a statue can be detected if it is close to the surface; it would be easier to detect if carved in igneous stone rather than marble or some other nonmagnetic stone.

Conductivity surveys can locate artifacts made of any metal. For example, lead pipes can be traced with this technique.

THE GEOPHYSICAL SURVEYS OF ELIZABETH K. RALPH

Elizabeth K. Ralph, who passed away in 1993, was a pioneer in the application of geophysical surveying to archaeology and an inspiration to this writer. Her excellent success in locating buried features at many archaeological sites in the Mediterranean region is particularly appropriate to detail in this review, since she received the AIA's Pomerance Award in 1986 for her contributions to archaeological science and her work is frequently referred to in *AJA*.

During the period from 1962 to 1976, Ralph did geophysical surveys at over 49 sites in 13 countries. Her principal and favorite geophysical instrument was the magnetometer (fig. 5), and her application of the cesium magnetometer showed how speed and precision could be combined for a successful survey.[44] Her sheer output—about 750,000 magnetic measurements that were plotted and contoured by hand—has never been equaled. She also carried out many surveys with resistivity meters and a seismograph.

The largest single survey that Ralph undertook was at the site of ancient Sybaris, in Italy, where the Greeks established a colony renowned for its "sybaritic" lifestyle. Over the period from 1962 to

[44] E.K. Ralph, "Comparison of Proton and Rubidium Magnetometer for Archaeological Prospecting," *Archaeometry* 7 (1964) 20–27.

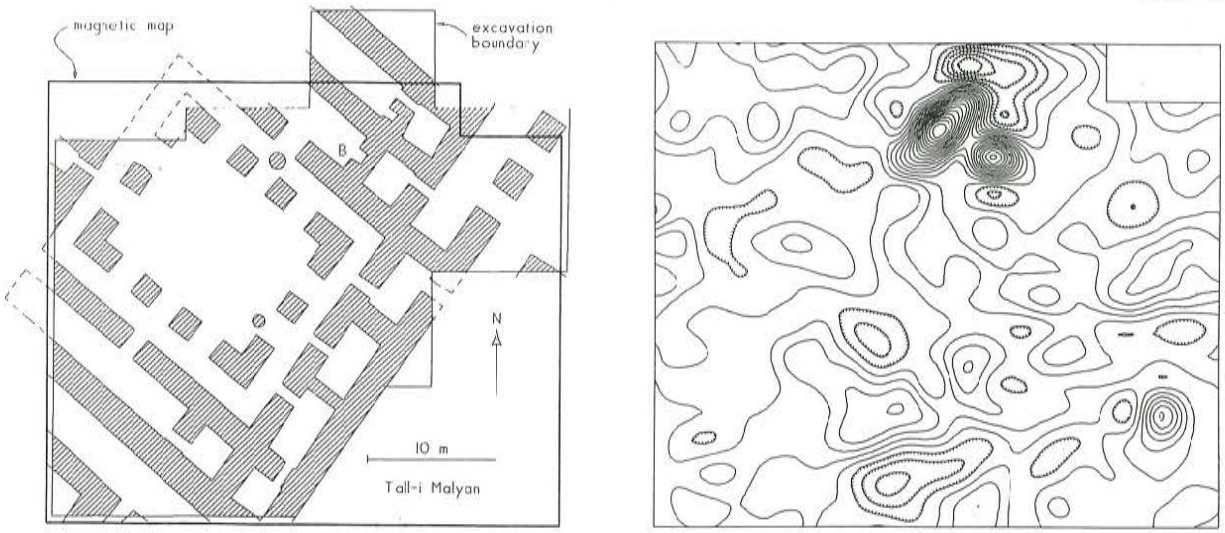

Fig. 6. Plan (left) of excavated room (B) in large building at Tall-i Malyan, Iran. The room, which was filled with burnt mudbrick wall material, was detected as the magnetic high near the top middle of the magnetic contour map (right), with intervals at 5 nanotesla. The magnetic measurements on which the contour map is based were spaced 2 m apart, and the cesium magnetometer's sensor was at a height of about 0.7 m above the ground. (Plan of building, courtesy W.M. Sumner)

1967, she worked on site in Italy for a total of about two years. She made between 300,000 and 400,000 magnetic measurements, which enabled the Archaic rooftiles of Sybaris to be located at a depth of 4 m beneath the alluvium that had accumulated over 2,500 years.[45]

Because of the huge area of search, the great depth of the structures, and the presence of shallower and more recent Roman structures, the survey at Sybaris was extremely difficult. The mapping of ancient Elis, a contemporaneous site in Greece, was easier and required fewer measurements (only 100,000!).[46] Ralph was able to show the plan of this city, for the brick and reused rooftiles used to construct the walls here were clearly delineated. While the written measurements look like a mass of dots, the contour lines of the magnetic maps trace the lines of underground walls.

Ralph did magnetic surveys at many other sites. In the former Yugoslavia in 1969, burnt Neolithic house floors were located.[47] At Malkata, Amenhotep III's palace in western Thebes, she located mudbrick structures buried in the sand (fig. 5). While these bricks had not been fired, the alluvial clay from the Nile River is quite magnetic and the bricks made from it were detectable in the nonmagnetic sand.[48]

At the ancient Elamite capital of Tall-i Malyan, Iran,[49] Ralph's magnetic survey was remarkably successful in locating significant archaeological remains in every area that was followed up by test soundings (fig. 6). Unfortunately, the Iranian revolution intervened to prevent further work at this site.

Although carried out 20–30 years ago, Ralph's geophysical surveys have never been surpassed in terms of their success or quality. Recent improvements in magnetometers enable surveys to be completed more quickly, but no significant increase in the accuracy of the measurements has been possible. Conductivity meters and ground-penetrating radar have been developed since Ralph did her surveys, and with these instruments, geophysical surveys can be carried out at a wider range of archaeological sites.

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[45] See F.G. Rainey, "The Location of Archaic Greek Sybaris," *AJA* 73 (1969) 260–73; and O. Bullitt, *Search for Sybaris* (Philadelphia 1969).

[46] E.K. Ralph, "Archaeological Prospecting," *Expedition* 11:2 (1969) 14–21.

[47] See A. McPherron and E.K. Ralph, "Magnetometer Location of Neolithic Houses in Yugoslavia," *Expedition* 12:2 (1970) 10–17.

[48] E.K. Ralph, "Magnetometer Survey at Malkata, Egypt," *MASCA Newsletter* 9:2 (1973) 3–5.

[49] W.M. Sumner, "Tall-i Malyan," *Iran* 12 (1972) 155–80; E. Carter and M.W. Stolper, "Middle Elamite Malyan," *Expedition* 18:2 (1976) 33–42.

Archaeobotany: Macroremains

NAOMI F. MILLER

Palaeoethnobotany (or the shorter term, archaeobotany) is the study of the "*direct* interrelationships between humans and plants for whatever purpose as manifested in the archaeological record."[50] No matter what the time period or geographical area, plants played an important role in human culture. As primary data about the natural environment, land-use practices, diet, architecture, and trade in exotic plant materials, plant remains also reflect many aspects of society, including social practices, such as eating, the organization of labor, and status differentiation.

The three major categories of archaeobotanical materials are macroremains, pollen, and phytoliths.[51] Macroremains are relatively large items that generally comprise the bulk of plant remains recovered from archaeological sites. They include seeds and seed-like plant structures, fruits, wood, leaves, tubers, etc. Typically, macroremains are recovered manually, by screening, and by flotation (fig. 7). Flotation enables the archaeologist to concentrate macroremains dispersed in the site matrix, usually by dissolving a soil sample in water.[52]

Fig. 7. Flotation system used to recover ancient plant remains at Gordion, Turkey, in 1988

No single category of remains provides a full picture of ancient plant use. When one considers the total amount of plant material intentionally brought to a site by ancient people (for food, fuel, fodder, construction, tools, and other artifacts), plus material unintentionally incorporated in the archaeobotanical record, one realizes that it is ordinarily the discards and residues of plant use that get deposited initially, a subset of which is eventually preserved (usually through carbonization, but sometimes under dry or waterlogged conditions).[53] Texts, too, are an important source of information that describe many aspects of the relationships between people and plants (e.g., agricultural treatises, receipts, recipes, and medical prescriptions). Yet such sources are often too limited or too general to provide more than a narrow window onto agricultural practices, the effects of land clearance, fuel-gathering, and irrigation, and all the other ways in which plants were integrated into the daily lives of ancient peoples. Thus, especially for the later periods, the information gleaned from texts complements, but does not supplant, that gained from detailed archaeobotanical studies.

Although archaeologists have been saving plant remains from archaeological sites since the mid-19th century, the systematic sampling of archaeological sediments by means of flotation is a relatively recent development. Prior to the pioneering work of Hans Helbaek[54] at Jarmo in Iraq, and later at Ali Kosh in southwestern Iran, botanists were brought in to identify obvious concentrations of plant remains, usually crops. It was not until the late 1960s that flotation techniques were brought to the attention of archaeologists in the Old and New Worlds, and

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[50] R.I. Ford, "Paleoethnobotany in American Archaeology," in M.B. Schiffer ed., *Advances in Archaeological Method and Theory* 2 (New York 1979) 285–336.

[51] Palynology is discussed in the next section of this review.

[52] *Paleoethnobotany: A Handbook of Procedures* (San Diego 1989) by D.M. Pearsall is a comprehensive, practical introduction to palaeoethnobotany.

[53] C.W. Haldane, "Shipwrecked Plant Remains," *BiblArch* 53:1 (1990) 55–60.

[54] H. Helbaek, "The Palaeoethnobotany of the Near East and Europe," in R.J. Braidwood and B. Howe, *Prehistoric Investigations in Iraqi Kurdistan* (Chicago 1960) 99–118; and Helbaek, "Plant-Collecting, Dry-Farming, and Irrigation Agriculture in Prehistoric Deh Luran," in F. Hole et al., *Prehistory and Human Ecology of the Deh Luran Plain* (Ann Arbor 1969) 383–426.

through the 1970s, flotation was not routinely practiced. Most of archaeobotanical work concentrated on the origins of agriculture, the major problem as defined in the United States by anthropologically trained archaeologists and in Europe by prehistorians. Now, in the 1990s, the aceramic Neolithic is increasingly well understood, but comprehensive syntheses of the later Neolithic and beyond have yet to be written. Even the early civilizations of the third millennium B.C., which have been given a fair amount of archaeobotanical attention, are poorly known. Later historical periods have been particularly neglected, probably because of undue reliance on written records.[55]

Several reviews of research in the Near East and Europe summarize decades of work on plant remains from sites dating between Palaeolithic and medieval times.[56] A detailed example from recent work at Gordion, a site that culturally straddled the classical world and the ancient Near East, illustrates the kinds of questions one can ask of archaeobotanical data.

RECENT RESEARCH AT GORDION

Gordion, located on the Sakarya River in central Turkey, was the capital of ancient Phrygia. Excavations early in this century and more recent research directed by Rodney S. Young between 1950 and 1973 were completed before the systematic search for plant remains became standard practice. Plant remains recovered by Young's team were primarily construction material and food remains from the massive Early Phrygian destruction level, the log structures at the base of the "Midas Mound" (Tumulus MM), other burial mounds, and tomb furniture, also from the Early Phrygian period (ca. 700 B.C.).[57] Renewed excavations in 1988 and 1989 and archaeobotanical study have begun to fill out the picture of ancient plant and land-use practices at Gordion between the Late Bronze Age and medieval times.[58]

Reconstructing Ancient Vegetation and Human Influence

Over the past 3,000 years, human activities have had a more profound influence on the vegetation of the Sakarya valley than climate.[59] Land clearance for fuel and agriculture, the grazing of domesticated animals, and, in the Phrygian period, construction seem to have had the cumulative but gradual effect of reducing whatever natural tree cover there was. Gordion lies at the edge of the central Anatolian steppe, where remnants of oak and juniper woodland and pine forest still exist. Based on the modern distribution of trees, we infer that the impressive juniper and pine timbers found in Phrygian burial mounds and the settlement probably originated in woodland 20–50 km away.

To trace the history of ancient vegetation in more detail, less dramatic evidence from occupation debris must be gathered and analyzed. This plant material, nearly all of which is carbonized, comes primarily from the remains of fuel (wood, brush, and dung) and consists of wood charcoal and charred seeds. Many species are found that are unknown from the tombs or from the constructional and food remains of the burnt buildings. Since fuel is rarely transported from far away, fuel remains enable one to monitor the vegetation growing relatively close to a settlement. At Gordion, the analysis showed a decline in juniper relative to oak. The virtual absence of juniper *fuel* in contemporary Phrygian deposits suggests that juniper timber had already become a fairly rare material, reserved for or limited to use in the royal tombs. Trees that characteristically replace the climax vegetation of oak, juniper, or pine, along with components of riparian forest, show a gradual increase between the Late Bronze Age and the medieval period, though they never surpass 20% by weight of the assemblage.

Brush and dung fuel are potential sources of seeds in the archaeobotanical record, and the charred seed

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[55] For a review of recent archaeobotanical research, see N.F. Miller, "The Near East," in W. van Zeist, K.-E. Behre, and K. Wasylikowa eds., *Progress in Old World Palaeoethnobotany* (Rotterdam 1991) 133–60.

[56] For a topically and geographically organized work that includes exhaustive discussions of the European archaeobotanical record, see van Zeist et al. (supra n. 55). *Domestication of Plants in the Old World* (Oxford 1988) by D. Zohary and M. Hopf provides a botanically oriented plant-by-plant discussion, and *Man's Role in the Shaping of the Eastern Mediterranean Landscape* (Rotterdam 1990) by S. Bottema, G. Entjes-Nieborg, and W. van Zeist is particularly informative on developments around the Mediterranean.

[57] E.g., H. Kayacık and B. Aytuğ, "Gordion Kral Mezarı'nın Ağaç Malzemesi üzerinde Ormancılık yönünden Araştırmalar (Recherches au point du vue forestier sur les matériaux en bois du tombeau royal de Gordion)," *İstanbul Üniversitesi Orman Fakültesi Dergisi* 18, series A (1968) 37–54; B. Aytuğ, "Le mobilier funéraire du roi Midas I," *PACT* 22 (1988) 357–68.

[58] M.M. Voigt, "Excavations at Gordion 1988–89: The Yassihöyük Stratigraphic Sequence," in D. French and A. Çilingiroğlu eds., *Proceedings of the 3rd International Anatolian Iron Age Symposium, 1990* (Oxford, in press); G.K. Sams and M.M. Voigt, "Work at Gordion in 1988," *XI. Kazı Sonuçları Toplantısı* 1 (Ankara 1990) 77–105; and Sams and Voigt, "Work at Gordion in 1989," *XII. Kazı Sonuçları Toplantısı* 1 (Ankara 1990) 455–70.

[59] Cf. S. Bottema and H. Woldring, "Anthropogenic Indicators in the Pollen Record of the Eastern Mediterranean," in Bottema et al. (supra n. 56) 231.

assemblage is a useful indicator of these alternative fuel sources; an increase in the ratio of seeds to charcoal suggests a decline in the use (i.e., availability) of tree wood. At Gordion, there is no dramatic shift in this ratio, which suggests that fuel use practices were relatively stable, despite some long-term disturbance in the tree cover.

Reconstructing Ancient Agricultural Practices

The seeds provide more than just evidence of fuel use. In the absence of cess deposits, seeds from burnt domestic structures provide the strongest evidence that a crop plant was grown for food, though fiber and fodder can usually not be ruled out.

Six-row barley and bread wheat dominate the crop seed assemblage in all periods. Einkorn wheat is a minor cereal, and rice occurs in only one medieval deposit. Lentils and bitter vetch comprise the bulk of the pulses. A burnt early Iron Age house had what appears to be baskets of barley, wheat, and bitter vetch on the floor. A small jar of tiny flax seeds found in the destruction level of Terrace Building 2A might be seed stock for the fiber plant, but the same room yielded small jars of other food crops, wheat, barley, and lentils, so the flax might have been human food. Grapes (a few seeds) were also found as were nutshells, perhaps from wild-growing almonds.

Plant remains may point to changes in irrigation practices, as indicated by crop choice, seed size/shape, and characteristic weeds. At Gordion, despite the unpredictable climate, very little "progress" is visible in the archaeobotanical record. For example, barley is more drought-tolerant than wheat, yet the proportion of these two crop plants remains constant through time. Irrigated grains tend to be plumper than unirrigated ones of the same species; at Gordion, size and shape of both wheat and barley are remarkably stable throughout the occupation. The expansion of a moist habitat—irrigation ditches or riverside vegetation—may be indicated by the apparent increase in the proportion of sedge seeds, which is consistent with the evidence of increased use of riparian vegetation. As trees by the river were cut, a sunny riverbank habitat would have opened up.

Stability characterizes Gordion crop choice. Small shifts in the proportion of einkorn wheat relative to six-row barley and bread wheat are therefore particularly intriguing. Einkorn was one of the earliest domesticated plants, but by 2000 B.C. it had dropped out of favor as an important cereal in the Near East.[60] In southern Europe, the presumed homeland of the Phrygians, it seems to have retained its value well into the Iron Age.[61] Thus, the apparent slight increase in einkorn coincidental with construction and ceramic shifts, suggestive of the Phrygian culture, may be further evidence of the arrival of these newcomers from Europe.[62]

CONCLUSION

Despite several decades of research, the full potential of archaeobotany for the investigation of ancient culture is yet to be realized. For both prehistoric and historical periods, plant remains enable us to assess human impact on the environment. As direct, site-specific evidence of agricultural and culinary activities, they can enrich our understanding of how people lived. Archaeobotanical research at Gordion is meant to show both skeptics and the converted how bits and fragments of charred remains help create a picture of the lives of ancient people and the landscape they shaped and inhabited.

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Ancient Palynology

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The study of micro- and macrofossils (including agricultural products such as carbonized hard grains—see the preceding section on Archaeobotany) in the Near East was stimulated by Robert J. Braidwood of the University of Chicago in the early 1960s. He sought to integrate archaeology and the natural sciences in his work on early prehistoric sites in Iran and Turkey. The botanical investigations of this proj-

[60] Miller (supra n. 55) 146–48.

[61] H. Kroll, "Südosteuropa," in van Zeist et al. (supra n. 55) 167, 174–75.

[62] Voigt (supra n. 58); R.C. Henrickson, "Politics, Economics, and Ceramic Continuity at Gordion in the Late Second and First Millennia B.C.," in W.E. Kingery ed., *Social and Cultural Contexts of New Ceramic Technologies* (Ceramics and Civilization 6, Westerville, Ohio 1993) 89–176.

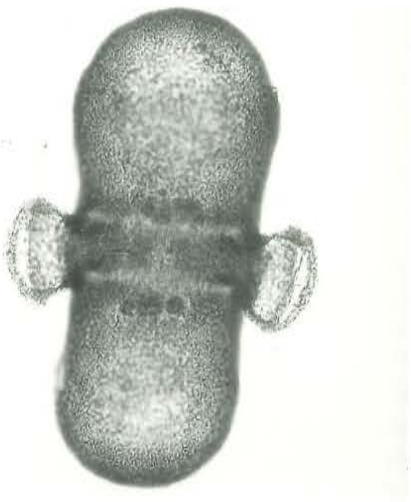

Fig. 8. Pollen grain of *Morina persica* of the teasel family, measuring ca. 100 μ in length (90× magnification), with prominent protuberances on the sides from which the pollen tubes grow. From a Bronze Age tin mine in Kestel, Turkey, excavated under the direction of Aslıhan Yener, this *Morina* grain is the only one recovered by the author in 30 years of palynological investigation.

ect were carried out by a Groningen University team led by Willem van Zeist, and were subsequently extended to many other regions of the Near East.[63]

An important aim of ancient palynological research is to reconstruct the palaeoenvironment of early humans, which includes the human impact on the environment. To obtain the optimal information from pollen samples, the nature of typical microfossils needs to be understood. Thousands of pollen grains (fig. 8) are precipitated on each square inch of ground per year. Unless they are preserved under anaerobic conditions (e.g., under water), pollen will very rapidly disappear. The various pollen types are not equally sensitive to degradation, some being far more resistant than others. The identifiability of different pollen types also varies; while some pollen retain their characteristic features even after degradation, other pollen are impossible to identify even under weakly oxidative conditions.

Other factors also need to be considered in any palynological investigation. For example, the gradually accumulating sediments of lakes, peatbogs, and swamps incorporate enormous numbers of pollen, which can be well preserved if kept constantly wet. Yet, these pollen need not correlate with the activities of ancient peoples, whose settlements and encampments can be located away from such bodies of water. Samples from the archaeological site itself, on the other hand, have the disadvantage that they are dominated by Liguliflorae, mostly yellow flowering composites, which comprise a relatively small percentage of the total pollen rain. Furthermore, the accumulation of debris in a Near Eastern tell is often the result of the disintegration and leveling of mudbrick houses. Such mudbrick is made from clay that has its own history, i.e., it may contain pollen that derives from a time preceding the structure in which it was used and which therefore cannot be used to reconstruct the contemporaneous palaeoenvironment.

Pollen samples from water sediments usually enable the general vegetational development of a region to be reconstructed. The best sequences occur where rainfall exceeds 300 mm per year. This isohyet appears to be the minimum for the formation of pollen-bearing sediments. An exception is a pollen core from the salt flats of Bouara on the Syrian-Iraqi border,[64] where precipitation amounts to only about 150 mm. The Bouara salt flats form part of the Khabur valley, a region that was densely inhabited during Assyrian times.[65] The Assyrians, who dry-farmed and irrigated the fields elsewhere in the Khabur, evidently used the Bouara exclusively for salt-winning.

The collection of pollen samples is done by manually coring the sediments. The samples are identified in the laboratory, using a light microscope, generally under 400× magnification.

PALAEOENVIRONMENTS IN PRE- AND POSTGLACIAL TIMES

Near Eastern pollen sequences or profiles (e.g., fig. 9) show a marked contrast in palaeoenvironmental development from the glacial period (Pleistocene) to postglacial (Holocene) times, i.e., pre- and post-10,000 B.P. (uncalibrated radiocarbon years). As dated by radiocarbon or by correlation with other

[63] See W. van Zeist and S. Bottema, *Late Quaternary Vegetation History of the Near East* (Beihefte zum Tübinger Atlas des Vorderen Orients A18, Tübingen 1991).

[64] W.H.E. Gremmen and S. Bottema, "Palynological Investigations in the Syrian Gazira," in H. Kühne ed., *Die rezente Umwelt von Tall Seh Hamad und Daten zur Umweltrekonstruction der assyrischen Stadt Dur-katlimmu* (Berlin 1991) 105–16.

[65] See Kühne (supra n. 64).

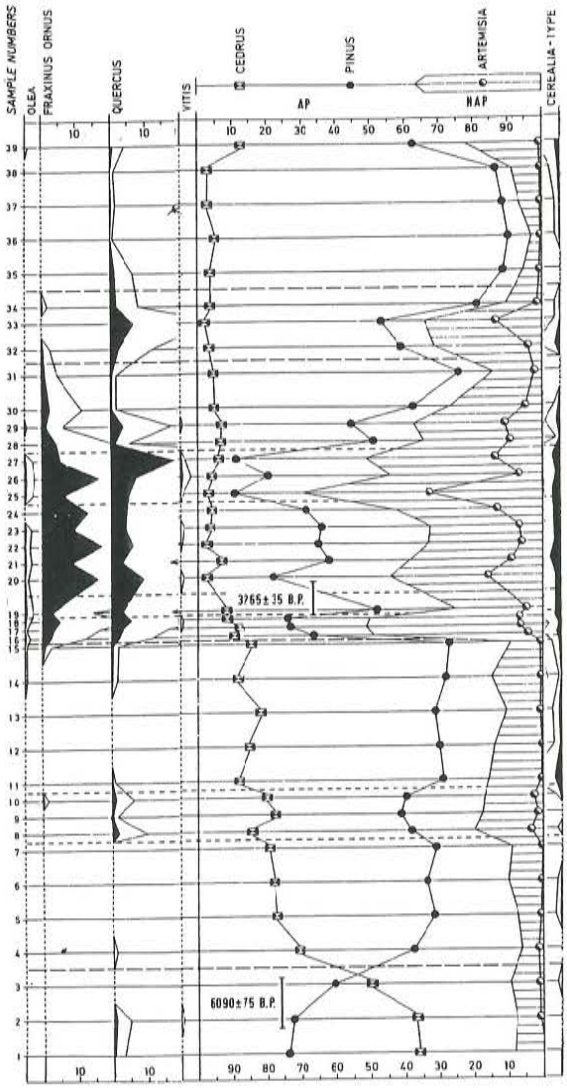

Fig. 9. Percentages of a selection of pollen types from a 5.5-m long core from Lake Beyşehir, Turkey, beginning about 6000 B.P. (bottom of the graph) and indicating an occupation phase, with greater amounts of edible fruits and nuts available, ca. 3200 B.P. (middle). The cumulative percentages of the most frequent arboreal types (AP) in each sample, *Cedrus* (cedar) and *Pinus* (pine), can be read along the top scale from left to right. On the left side of the diagram are shown less frequent arboreal types, including *Olea* (olive), *Fraxinus ornus* (manna-ash), *Quercus* (oak), *Vitis* (grape); individual percentage scales read from left to right. Non-arboreal types (NAP), including *Artemesia* (composite herbs and shrubs) and *Cerealia*-type (cereals), are shown to the right; their percentages are read along the bottom scale from right to left. The sum of the less frequent arboreal types is the difference between the cumulative percentages of AP and NAP. Dashed horizontal lines separate periods having similar vegetation and subject to similar environmental constraints, as inferred by the palynologist.

dated pollen profiles, the general picture for lower elevations (e.g., the Ghab valley of northwest Syria or Yenişehir in the Bursa area of western Turkey), as well as the higher Anatolian plateau of Turkey and the Zagros Mountains of western Iran, is that of a steppe landscape giving way to forest. This climatically induced change is locally influenced by developing farming communities, but the general trend of steppe herb pollen gradually being replaced by tree pollen has been demonstrated.

The process starts as early as 15,000 B.P. in northern Israel where relatively dense Tabor oak forests established themselves, only to decrease abruptly around 11,500 B.P. A climatic belt of rain that encouraged tree growth apparently moved farther north and east, leaving Israel much drier after this time.[66] The moist zone arrived in the Pisidian Lake district of southwestern Anatolia around 9000 B.P. In eastern Turkey, the Van district shows some increase in deciduous oaks at about 7000 B.P. In northwestern Iran, optimal conditions for tree growth were established around 5500 B.P. The forest development of the Pontic part of Turkey is very similar to that of northern Greece and large areas of Europe. If such vegetational patterns are translated into climatic terms, two main systems can be observed: a general European pattern that is uniform over a large area, and a shifting system that moves from the southern part of the Near East to the north and northeast. The latter moisture belt might have been caused by the gradual retreat of the large ice cap in northern Europe. This retreat, which started in the west and south, is likely to have caused a shift in the polar front that contributed to a moving moisture belt in the Near East.

EARLY AGRICULTURE

The pollen record also informs us about the impact of ancient man on the vegetation of a region, as well as the kinds of agriculture that were initiated during the Holocene period. In what kind of landscape did ancient agriculture develop, and what were the consequences for the environment? Pollen analysis provides answers to such questions if so-called indicator types (pollen that can be ascribed to human activity), which derive either from crops (pri-

[66] U. Baruch and S. Bottema, "Palynological Evidence for Climatic Changes in the Levant ca. 17,000–9,000 B.P.," in O. Bar-Yosef and F.R. Valla eds., *The Natufian Culture in the Levant* (International Monographs in Prehistory, Archaeological Series 1, Ann Arbor 1991) 11–20.

mary types) or from weeds (secondary types), are present. The available pollen profiles generally show that these types increase slowly during Neolithic times (near the beginning of the Holocene period). Sometimes agriculture is known to have been practiced, as evidenced especially by carbonized cereal grains of wheat and/or barley that are known to have been early domesticates, but indicator pollen are lacking. This circumstance often arises when pollen types of the wild ancestors of our domestic cereals cannot be distinguished from those of a group of wild grasses. In addition, wheat and barley often disseminate little pollen into the air, because the pollen of these self-fertilizers remain in their glumes. Bread made from these cereals actually contains far more pollen than what is recovered from an ancient context exposed to pollen rain.

In sediment pollen profiles with no plants of economic importance represented, types related to the grazing of animals are often found. Weedy pollen types, which occur in the Near East and Europe (e.g., *Plantago lanceolata*, *Sanguisorba minor*, and *Rumex*) are good indicators.

Another noticeable change in pollen profiles that can be attributed to human impact on the environment is a decrease in forest pollen species. Around 4000 B.P., the first effects of the degradation of forests, which were burned for pasture and grazing land, are evident over large areas of the Near East. This development intensifies around 3200 B.P. Along the Mediterranean coast, the typical xerophytic vegetation replaces the former deciduous oak forest. In western Anatolia, arboriculture based on walnut, sweet chestnut, manna-ash, grape, and olive appears. At the same time, the plane tree spreads all over central and western Anatolia.[67]

CONCLUSIONS

An important focus of future palynological research in the Near East will be to define the specific constraints for human settlement, especially in the forest-steppe regions. In general, the pollen evidence needs to be integrated with and interpreted in light of the results from other disciplines (e.g., archaeobotany) and the available archaeological data to draw well-based conclusions.

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[67] Bottema and Woldring (supra n. 59) 231–64.

Faunal Analysis with a Focus on Anatolia

HITOMI HONGO AND RICHARD H. MEADOW

INTRODUCTION

Analysis of animal bones (faunal analysis) has become increasingly common in Near Eastern archaeology.[68] Much of the first research focused on identifying animals exploited by Palaeolithic hunters and on the beginnings of animal domestication during the Neolithic. Recently, however, increasing numbers of faunal studies have been carried out on sites later than the Neolithic. Because analysis of animal bones began as early as the 1930s in Anatolia, that area provides a useful source of examples to underline some of the possibilities and problems of research that have changed over time.

GOALS

Perception of what faunal analysts do and should do varies among archaeologists and even among faunal specialists themselves. At one end of a continuum is faunal analysis as a set of procedures to identify and record animal bone remains with a view toward documenting the history of human impact on animals. People who work in this way often call themselves "archaeozoologists." At the other end is analysis and interpretation of faunal remains in the context of particular archaeological problems with a focus on interactions between humans and animals within specific social and cultural contexts. In-

[68] This essay is respectfully dedicated to the memory of Berrin Kuşatman (Doğan), whose tragic death at the age of 36 in May 1993 robbed Turkey of a dedicated faunal analyst with a bright future. Her Ph.D. dissertation titled "The Origin of Pig Domestication with Particular Reference to the Near East" (Institute of Archaeology, University College London, 1991) represents a remarkable piece of research on a difficult topic.

Fig. 10. Faunal analysis at Kaman Kalehöyük, Kırşehir, Turkey: a) In the laboratory, measuring a distal humerus, and b) on the excavation, uncovering a late second-millennium B.C. bone dump. (Courtesy R.H. Meadow)

vestigators who approach the field in this fashion often call themselves "zooarchaeologists." There is a parallel continuum in the ways that faunal analysts are related to excavation projects. Some have tended to work as technicians/specialists who identify bones and present the results to archaeologists. Others try to be an integral part of projects and employ a more holistic approach to analysis and interpretation.[69]

In faunal studies, recovery techniques and archaeological context are crucial (fig. 10). Animal bones themselves, unlike potsherds and other artifacts, generally do not contain intrinsic clues to dating or social/cultural affiliation (unless they can be characterized isotopically). Therefore faunal remains from mixed or disturbed contexts are best avoided, because the data may be misleading if they are interpreted uncritically. In addition, there are various cultural practices and postdepositional factors that can affect the distribution of animal bones across an archaeological site. Careful recovery incorporating a program of sampling and sieving combined with detailed information about archaeological context of the material will help the investigator to evaluate the biases involved. Ideally, the faunal analyst should be brought into a project during the research design stage to help develop an effective sampling method while taking into consideration time, budget constraints, and the overall goals of the project. At whatever stage an analyst becomes involved in a project, however, it is important that he or she be fully informed about the stratigraphy of the site, the details of archaeological context, and the sampling methods employed.[70]

What can be classed under the rubrics of "experimental" or "actualistic" studies form important aspects of faunal research. These include preparing a modern comparative collection to assist in identification of the archaeological fauna, carrying out studies on modern animal keeping and hunting or fishing practices in the local area in order to understand possibilities and limitations, and testing the efficacy of recovery techniques. An example of significant work in these areas has been that of Sebastian Payne in Anatolia and southeastern Europe. In a study of sampling methods, he demonstrated that bones of medium and small animals can be significantly underrepresented in a hand-picked faunal assemblage when compared to a sieved assemblage.[71] For the material from Aşvan Kale, he developed a technique for recording tooth wear in sheep and

[69] S.J.M. Davis, *The Archaeology of Animals* (London 1987) provides a good introduction to some of what has been accomplished in the field as well as a useful bibliography. For an introduction to the basic techniques for identifying mammal bones and teeth, see S. Hillson, *Mammal Bones and Teeth* (London 1992); note, however, the author's warning on the cover of the book that "it should be used in conjunction with a reference collection of bones and teeth and with the help of an experienced zooarchaeologist." This is true of all published guides to bone identification of which there are many, the best for Europe and the Near East, however, still being the now out-of-print bilingual *Atlas of Animal Bones/Knochenatlas* (Amsterdam 1972) by E. Schmid.

[70] R.H. Meadow, "Animal Bones: Problems for the Archaeologist together with Some Possible Solutions," *Paléorient* 6 (1980) 65–77.

[71] S. Payne, "Partial Recovery and Sample Bias: The Results of Some Sieving Experiments," in E.S. Higgs ed., *Papers in Economic Prehistory* (Cambridge 1972) 49–64.

goats and, subsequently, studied tooth wear patterns in hundreds of living Angora goats in order to be better able to determine age at death of animals represented in the archaeological record.[72] From aging data such as these, it is possible to describe a "kill-off pattern" that reflects hunting or husbandry practices employed in the past.

ANATOLIAN FAUNAL STUDIES

In Anatolia, modern faunal research can be said to have begun in the late 1960s with the work at Çayönü, Suberde, and Can Hasan.[73] At each of these Neolithic sites, study of the animal remains was closely coordinated with other aspects of the projects, and faunal analysts were present on site for at least part of the excavation. Such work has shown that the transition from hunting to husbandry in Anatolia took place between about 7000 and 6000 B.C. in the context of settled agricultural villages. The keeping of domestic animals was not immediately accepted everywhere, however. At a number of contemporary sites (e.g., Aşıklı and Cafer Höyük), the faunal remains came from wild relatives of the stock that was already being kept and bred in captivity elsewhere.[74]

At sites of later periods where faunal remains are dominated by domestic forms, research focus is on husbandry practices and the nature of animal economies. Topics include selective breeding, site provisioning, exchange of animal products, and animal use by different social groups. Investigators recognize that ethnicity, social hierarchy, and differences in accumulation of wealth can affect the distribution and consumption of meat and other animal products, and they have even employed faunal remains to monitor the course of state formation.[75]

Unfortunately, faunal remains often have been ignored at sites of the Bronze Age and later. Research at such sites traditionally has focused on texts, architecture, and objects of art and on the establishment of chronology, and little attention has been paid to questions of subsistence. There is the tendency to think that we are already well informed about the kinds of animals and their uses in early historical times, because trade in livestock and animal products and aspects of animal sacrifice are described in ancient texts. In reality, however, very little is known about practices of animal keeping and consumption, especially the practices of the general public as opposed to those of the elites.

For Anatolia, most studies of animal bones of the protohistoric and historical periods have been archaeozoologically oriented. During the 1970s and 1980s, German researchers published data on large assemblages of animal bones from Boğazköy, Fikirtepe, Hassek-Höyük, Korucutepe, Lidar Höyük, Norşun-Tepe, and Demircihöyük.[76] They usually presented species lists and skeletal part frequencies, discussed kill-off patterns for domestic animals and changes in animal husbandry through time, and used measurement data to characterize animal size and proportions. There was little discussion, however, of variability in the distribution of faunal remains across a site, with the archaeological period being the principal unit for defining an assemblage. In addition, as excavation and recovery techniques were seldom mentioned, intersite comparisons required assumptions of comparability that may not be justified.

Faunal research is even rarer in later periods, such as the Hellenistic, Roman, and Islamic periods in Anatolia. Although there is an exceptional study of the "Sacrificial Layer" at Halikarnassos,[77] the practice of animal husbandry during the Iron Age and medieval period at the site remains largely unknown.

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[72] S. Payne, "Kill-off Patterns in Sheep and Goats: The Mandibles from Aşvan Kale," *AnatSt* 23 (1973) 281–303; and E. Deniz and S. Payne, "Eruption and Wear in the Mandibular Dentition as a Guide to Ageing Angora Goats," in B. Wilson, C. Grigson, and S. Payne eds., *Ageing and Sexing Animal Bones from Archaeological Sites* (Oxford 1982) 155–205.

[73] B. Lawrence, "Principal Food Animals at Çayönü," in L.S. Braidwood and R.J. Braidwood eds., *Prehistoric Village Archaeology in South-Eastern Turkey* (Oxford 1982) 175–99; D. Perkins, Jr., and P. Daly, "A Hunters' Village in Neolithic Turkey," *Scientific American* 219:5 (1968) 97–106; D.H. French, "Excavations at Can Hasan III 1969–1970," in E.S. Higgs ed., *Papers in Economic Prehistory* (Cambridge 1972) 181–90. Unfortunately, only Çayönü has been published in any detail.

[74] D. Helmer, *La domestication des animaux par les hommes préhistoriques* (Paris 1992).

[75] P. Wattenmaker, "The Organization of Production and Consumption in a Complex Society: A Study of a Village Site in Southeast Turkey," *MASCAJ* 4 (1987) 191–203; P. Wattenmaker and G. Stein, "Early Pastoral Production in Southeast Anatolia: Faunal Remains from Kurban Höyük and Gritille Höyük," *Anatolica* 13 (1986) 90–96; M.A. Zeder, *Feeding Cities: Specialized Animal Economy in the Ancient Near East* (Washington, D.C. 1991).

[76] Publications listed in A. von den Driesch and J. Schäffer, *20 Jahre Institut für Palaeoanatomie, Domestikationsforschung und Geschichte der Tiermedizin der Universität München 1965–1985* (Munich 1985); J. Boessneck, *25 Jahre Institut für Palaeoanatomie, Domestikationsforschung und Geschichte der Tiermedizin der Universität München 1965–1990* (Munich 1990).

[77] F. Højlund, "The Deposit of Sacrificed Animals at the Entrance to the Tomb Chamber," and K. Aaris-Sørensen, "Zoological Analysis," in *The Maussolleion at Halikarnassos* 1: *The Sacrificial Deposit* (Copenhagen 1981) 21–90 and 91–110, respectively.

RESEARCH POTENTIAL

The Middle East has always been a crossroads for peoples and cultures that are sometimes documented in the texts, but are usually difficult to trace archaeologically. Faunal remains can be an effective tool in this respect, because people belonging to all social groups, and not just the elites, discard bones; and how people raise animals, as well as what they eat, can reflect ethnic and social differences. The following kinds of observations are useful in documenting culture-specific practices of animal keeping:

1) The use of domestic animals, for traction or for their various products (meat, milk, wool, hides), and their contribution to the pastoral economy can be seen in the range of animal species used, their relative importance, and the kill-off pattern employed. The presence or absence of certain species (e.g., pigs) can indicate ethnic differences.

2) Season of slaughter can be determined by examining incremental structures in the cementum of teeth through the preparation of microscopic thin-sections.[78] Since animals often appear in association with gods in season-specific ritual contexts in ancient texts and art, it may be possible in some instances to identify the remains from sacrifices or other periodic events through seasonality studies and perhaps even identify the sacrificial occasion.

3) The presence of foreign species may reflect trade or alliances between geographically distant places and even the migration of peoples. The introduction of the domestic horse into Anatolia, perhaps through the Caucasus, is a good example.

4) Change in size and body proportions of domestic animals through time can show whether different breeds of animals were developed or introduced. Similar observations on wild animals can help identify human pressure on the environment.[79]

5) Frequencies of different body parts and butchery techniques can be related to ethnic differences and to different types of provisioning.

6) Intrasite distributions can provide information on social and functional differences. Animals associated with higher status (e.g., horses) or particular activities (e.g., camels) may only be found at specific locations.

Thus, there is great potential in the study of animal bones from archaeological sites of all periods, to shed light not only on animal exploitation patterns but on social/cultural practices that other archaeological materials cannot reveal. It is particularly regrettable that there is general indifference to animal bone studies among many archaeologists working at early historic and medieval sites in the Middle East.[80] We hope that in the next decade faunal analyses will become more common and better integrated into research strategies developed to investigate the nature of complex societies.[81]

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Dendrochronology

PETER IAN KUNIHOLM

Over 6,000 years of tree-ring chronologies covering much of the period back to about 7500 B.C. have been developed over the past 20 years for the Aegean, Balkans, and Near East. The goal is to construct an unbroken chronology from the Neolithic to the present against which archaeologists, art historians, and anthropologists may date finds of wood or charcoal, theoretically to within one year.

METHOD

Tree-ring sequences from trees that grow in a seasonal climate, i.e., with one growth increment per

[78] D.E. Lieberman and R.H. Meadow, "The Biology of Cementum Increments (with an Archaeological Application)," *Mammal Review* 22 (1992) 57–77.

[79] The professional standard for bone measurements is A. von den Driesch, *A Guide to the Measurement of Animal Bones from Archaeological Sites* (Peabody Museum Bulletin 1, Cambridge, Mass. 1976).

[80] One exception is the excavations of the Middle East Cultural Center in Japan at Kaman Kalehöyük where the field director, Sachihiro Omura, has been particularly supportive of all kinds of bioarchaeology. We wish to thank Dr. Omura and the MECCJ for supporting our own participation in the project.

[81] The professional society for Archaeozoology/Zooarchaeology is the International Council for Archaeozoology (ICAZ), which can be contacted c/o Dr. A.T. Clason, General Secretary, Biologisch-Archaeologisch Instituut, Poststraat 6, 9712 ER Groningen, The Netherlands. Bibliographies are compiled each year and published in the journal of ICAZ, *ArchaeoZoologia* (Grenoble, France).

year, with the size of that growth dependent upon some climatic stimulus such as cold in the polar regions, drought in the Aegean, and various combinations of the two stimuli in regions in between, can be compared so that these increments, more popularly known as "rings," can be dated to the calendar year in which they were formed. Crossdating, matching patterns of ring growth from one tree to another and assigning rings to specific years, is possible only among trees growing in the same general climatic region. Crossdating can sometimes be achieved in spite of human interference to ring growth by thinning of stands, resin gathering, fire damage, and other traumas such as severe weather effects, pollution, lightning damage, etc., not to mention shaping of the wood at the time of construction and decay afterward. Both visual and statistical techniques are employed to guarantee the accuracy of the matches. In addition to simple ring-width analysis, X-ray densitometric methods are used to reconstruct past environmental conditions.[82] Wood or charcoal samples taken from standing buildings or excavated from archaeological sites can be crossdated with each other and with wood from living trees to extend the tree-ring chronology beyond the date of the oldest ring of the oldest living tree in the region. Dendrochronology is the only archaeometric technique for which determination of absolute dates accurate to the year is either theoretically or practically possible. For a thorough treatment of recent progress in dendrochronological and dendroclimatological work worldwide, see F.H. Schweingruber, *Tree Rings: Basics and Applications of Dendrochronology* (Boston 1988).

DENDROCHRONOLOGY IN THE AMERICAN SOUTHWEST AND IN EUROPE

Tree-ring studies have been a staple of anthropological investigation in the American Southwest[83] since the early decades of this century and in Europe since World War II. The bristlecone pine chronology of the American Southwest now exceeds 8,500 years with the possibility that up to 3,000 floating years will be added in the reasonably near future. The European oak and pine chronology, a composite of work done in Germany and Northern Ireland, is now over 11,000 years long.[84] Of particular interest to many *AJA* readers is the recent development of a 1,000-year oak chronology in Poland, which has demonstrated that panel paintings in Western collections, signed by artists such as Rubens, Rembrandt, etc., were painted on oak boards imported from Gdansk in the eastern Baltic.[85]

Significant work, but outside the scope of this report, is going on elsewhere: some archaeological, some climatological, and some palaeoclimatological. Notable progress has been made in recent years in South America with the development of long chronologies from *Fitzroya cupressoides* in the vicinity of the Patagonian glaciers, in China with attempts to link the tree-ring record with the Chinese archival records, in Russia with the study of tree growth at the northern timberline, and in Spain with the study of medieval monuments.

DENDROCHRONOLOGY IN THE AEGEAN

My own work has been focused on the Aegean for the last 20 years. Progress as of spring 1993 is shown in figure 11. We have about 6,000 years of chronologies spread out over the last 9,500 years in a region bounded by the Turkish-Georgian frontier in the east, the mountains of northern Lebanon in the south, including all of Turkey, Cyprus, Greece, parts of Bulgaria and the former Yugoslavia, and extending to the instep of the Italian boot at Mt. Pollino in Calabria. Whether we can push northward into the Crimea, northeastward into the Caucasus, and southward into northern Syria and other Near Eastern countries remains to be seen. Mesopotamia and Iran are for the moment inaccessible, but may some day yield useful information. We expect imported cedar and juniper from the Lebanon, found in Egypt, to crossdate with Anatolian chronologies.

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[82] F.H. Schweingruber, H.C. Fritts, O.U. Bräker, L.G. Drew, and E. Schär, "The X-Ray Technique as Applied to Dendroclimatology," *Tree-Ring Bulletin* 38 (1978) 61–91.

[83] For a recent summary, see J.S. Dean, "Dendrochronology," in M.R. Zimmerman and J.L. Angel eds., *Dating and Age Determination of Biological Materials* (London 1986) 126–65.

[84] J.R. Pilcher, M.G.L. Baillie, B. Schmidt, and B. Becker, "A 7,272-Year Tree-Ring Chronology for Western Europe," *Nature* 312 (1984) 150–52; and now Becker, "An 11,000-Year German Oak and Pine Dendrochronology for Radiocarbon Calibration," *Radiocarbon* 35 (1993) 201–13. For a recent archaeological application, which typifies the uses of the method, see B. Schmidt, H. Köhren-Jansen, and K. Freckmann, *Kleine Hausgeschichte der Mosellandschaft* (Cologne 1990).

[85] D. Eckstein, T. Wazny, J. Bauch, and P. Klein, "New Evidence for the Dendrochronological Dating of Netherlandish Paintings," *Nature* 320 (1986) 465–66. Also see Klein and Wazny, "Dendrochronological Analyses of Paintings of Gdansk Painters of the 15th to the 17th Century," *Dendrochronologia* 9 (1991) 181–91.

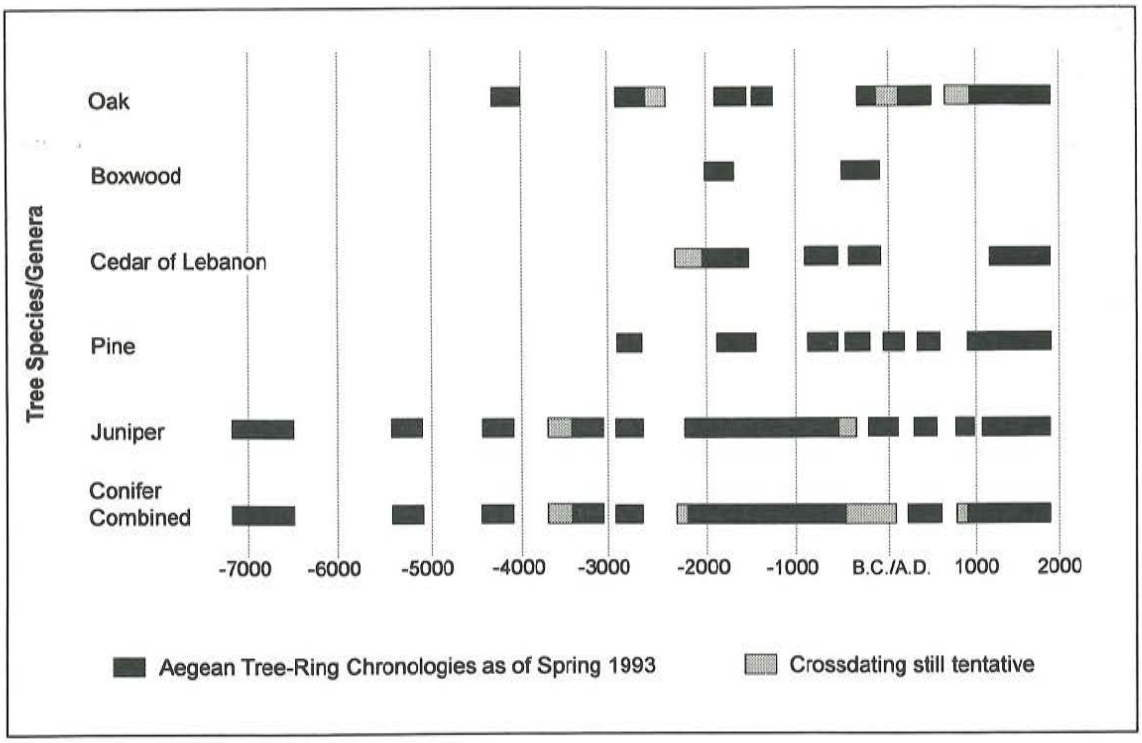

Fig. 11. Schematic representation of current Aegean dendrochronologies by tree species and/or genera. Note that "Conifer Combined" includes pine, cedar, and juniper.

Absolute chronologies for several genera of trees extend back for a millennium. Our oak sequence ends in A.D. 927. An eighth/ninth-century gap in the oak chronology may be filled by timbers from Amorium that were collected during the summer of 1993. A post-Justinianic gap exists just after the primary timbers from St. Sophia in Istanbul were cut. Another gap exists around the time of Constantine. Indeed, the millennium from roughly 500 B.C. to A.D. 500 is the most problematic of the last 4,200 years, although the first half may have been sorted out by the recent construction of a 513-year ring sequence from boxwood timbers in the Comacchio (Ferrara) shipwreck.[86] The sequence, with which a number of other ring chronologies crossdate, is dated to the last decades B.C. by three and a half tons of lead ingots stamped with the name AGRIPPA. A 1,761-year continuous ring sequence from around 2259 B.C. to around 498 B.C. is the longest we have. Early Bronze Age sequences are still under construction (see *Studia Troica* III, Tübingen 1993). For the prehistoric period, the most notable advance in the last year has been the development of almost 700 years of chronologies for the Neolithic site of Çatal Hüyük.

PRACTICAL MATTERS

For the dendrochronological method to succeed, long ring sequences are needed. We have measured junipers with as many as 918 annual rings. Çatal Hüyük charcoal fragments no larger than a half-golfball have as many as 250 rings preserved. Crossdating material like this is relatively easy. Trying to date samples with fewer than 100 rings, on the other hand, is generally not worth doing. Quantities are important. A set of 100 samples is vastly preferable to a set of 10, and single samples are to be avoided except in desperation. One cannot tell from internal evidence whether a single sample has been reused from an earlier construction, cut particularly for the purpose to which it was finally put, or is some later repair. Species are important. Oak, pine, juniper,

[86] F. Berti ed., *Fortuna Maris: La nave romana di Comacchio* (Bologna 1990); P.I. Kuniholm, C.B. Griggs, S.L. Tarter, H.E. Kuniholm, and M.I. Pezzo, "A 513-Year *Buxus* Dendrochronology for the Roman Ship at Comacchio (Ferrara)," forthcoming.

fir, boxwood, yew, spruce, and occasionally chestnut have been crossdated. Olive is impossible to work with, as are willow, poplar, and fruit trees. Large rings in these genera may mean merely that the gardener in the orchards in which they grew was unusually industrious that year. Cypress is usually undatable because the latewood cannot easily be distinguished from an individual annual ring. Finally, the condition of the sample is important. If the bark is present, the precise felling year may sometimes be determined. If some sapwood rings are present, only an estimate of the felling date may be made. If only heartwood is present, the date of the last preserved ring is, at best, a terminus post quem date.[87]

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Radiocarbon Calibration: Current Issues

S.G.E. BOWMAN AND M.N. LEESE

Radiocarbon dating has made a major contribution to archaeology for more than 40 years. For at least the last decade and a half, an immense amount of effort has been invested in providing calibration curves, in ensuring and evaluating data quality, and in interpreting results. The sheer volume of information is bewildering and much of it is seemingly complex, especially as new data are often presented without reference to the implications for archaeological application. In this review we are concerned only with the calibration of radiocarbon dating results and particularly with the status of recent calibration data and the emergent use of Bayesian statistics.

It must be stressed that calibration is often viewed as a final step, requiring thought only after the radiocarbon results have been supplied by the laboratory. On the contrary, the need for, and effect of, calibration are essential considerations in the sampling strategy. They may even influence the choice of laboratory, for example, if high precision proves necessary. Discussion among the archaeologist, radiocarbon scientist, and statistician is needed virtually from the moment the excavation is mooted. Only then can the correct type, size, and number of samples be dated for key contexts having well-understood sample-context-event associations.[88] The archaeologist can also assess the funding needed, the support he or she will receive in the interpretation of the radiocarbon chronology, and the quality of work produced by a given laboratory.[89]

The need for accurate results (i.e., those with no systematic bias) is self-evident, and every laboratory ought to be able to provide evidence for its accuracy. Equally important is the need to estimate realistically the precision (i.e., the random variability) of the results, since an assessment of this, together with the error on and shape of the calibration curve in the region of interest, determines the calendar age range(s). Use of an error multiplier is often suggested because of concern that the quoted error, which may be based only on counting statistics, does not fully reflect true variability (assessed by replication experiments or intercomparisons between laboratories). As an alternative, the current update of the program CALIB suggests the incorporation of ad-

[87] A readily accessible survey is P.I. Kuniholm and C.L. Striker, "Dendrochronological Investigations in the Aegean and Neighboring Regions, 1983–1986," *JFA* 14 (1987) 385–98. More recent summaries are P.I. Kuniholm and M.W. Newton, "A 677 Year Long Tree-Ring Chronology for the Middle Bronze Age," in *Studies in Honor of Tahsin Özgüç* (Ankara 1990) 279–93; P.I. Kuniholm, S.L. Tarter, M.W. Newton, and C.B. Griggs, "Preliminary Report on Dendrochronological Investigations at Porsuk/Ulukışla, Turkey 1987–1989," *Syria* 69 (1992) 379–89; and P.I. Kuniholm, "A Date-List for Bronze and Iron Age Monuments Based on Combined Dendrochronological and Radiocarbon Evidence," *Aspects of Art and Iconography—Anatolia and Its Neighbors: Studies in Honor of Nimet Özgüç* (Ankara 1993) 371–73.

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[88] See, e.g., S. Bowman, *Radiocarbon Dating* (London 1990); S. Bowman and N. Balaam, "Using Radiocarbon," *Antiquity* 64 (1990) 315–18.

[89] E.M. Scott, M.S. Baxter, D.D. Harkness, T.C. Aitchison, and G.T. Cook, "Radiocarbon: Present and Future Perspectives on Quality Assurance," *Antiquity* 64 (1990) 319–22.

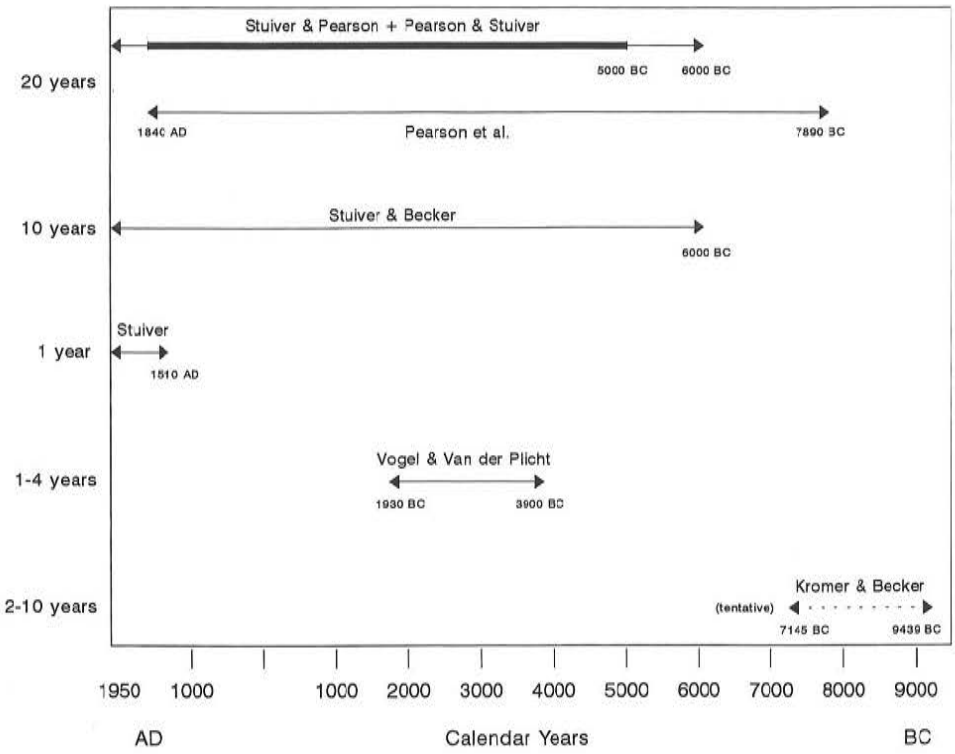

Fig. 12. Summary of calibration curves based on the 1993 *Radiocarbon* calibration issue (vol. 35:1), showing the date ranges covered and the number of tree rings used to construct the data points on each curve. Notes: 1) These data have largely superseded previous curves; the precision is typically ± 20 radiocarbon years back to about 6000 B.C., and ± 30 for older samples. 2) For the period 5000 B.C.–A.D. 1950 shown as a broader shaded line, the Belfast and Seattle data (Stuiver and Pearson and Pearson and Stuiver, respectively) agree statistically and are totally independent, being based on different dendrochronologies: these data, at least, are likely to be internationally recommended at the 1994 radiocarbon conference. Beyond 5000 B.C.: a) most measurements are based on the German oak sequence; b) the German pine linkage to the oak chronology is tentative (Kromer and Becker); c) there are statistically significant differences between laboratories for some time intervals; and d) other data (e.g., Linick et al., *Radiocarbon* 28 [1986] 943–53) provide cross-checks for some, relatively short, time periods. 3) Vogel et al. (*Radiocarbon* 35 [1993] 73–86) suggest that 41 ± 5 radiocarbon years should be subtracted from southern hemisphere results prior to calibration. 4) Also see Bard et al. (*Radiocarbon* 35 [1993] 191–200) for a uranium-series versus ^{14}C results for corals back to 30,000 B.P.

ditional laboratory error terms.[90] Somewhat inexplicably, however, the values suggested are the errors on a long superseded calibration curve; thus, we strongly recommend against this procedure. While it may seem better to over- rather than underestimate precision, in fact, this may not be erring on the side of caution. For example, a χ^2-test[91] (a statistical test of "agreement") could give an entirely erroneous confirmation of assumed contemporaneity. Again, only the laboratory itself can give the necessary information on the reliability of its error estimates and should be requested to do so.

CALIBRATION DATA

The publication in 1986 of a calibration issue of *Radiocarbon* (vol. 28:2B) and recommendation[92] of the consensus curves of the Belfast and Seattle laboratories for the period 2500 B.C.–A.D. 1950 was a considerable breakthrough. This provided a much-needed single, and seemingly definitive, calibration curve with the promise of its extension to earlier periods. The picture presented in the 1993 *Radiocarbon* calibration issue (vol. 35:1), however, appears considerably more complex. Figure 12 summarizes

[90] M. Stuiver and P.J. Reimer, "Extended ^{14}C Data Base and Revised CALIB 3.0 ^{14}C Age Calibration Program," *Radiocarbon* 35 (1993) 227.

[91] See G.K. Ward and S.R. Wilson, "Procedures for Comparing and Combining Radiocarbon Age Determinations: A Critique," *Archaeometry* 20 (1978) 19–31. Their "Case I," which assumes *a priori* evidence for contemporaneity, is relevant. "Case II" is unrealistic, as it does not take account of "wiggles" in the calibration curve.

[92] W.G. Mook, "Business Meeting: Recommendations/Resolutions Adopted by the Twelfth International Radiocarbon Conference," *Radiocarbon* 28 (1986) 799.

some of the 1993 curves based on dendrochronology. At least three of the data sets contain revisions of previous data, the maximum correction being about 30 radiocarbon years. Regrettable though the need for these changes may be, they illustrate the extreme care taken by the high-precision laboratories to check and recheck their experimental procedures and resultant data. Neither the revision of data nor the apparent proliferation of calibration curves should be taken as an excuse, as was previously prevalent, not to calibrate.

In choosing a calibration curve, it is best to match the age span of the sample to the time interval between points on the curve. Curves based on single-year samples are limited, but it has been shown that calibration of a single-year sample against decadal or bidecadal curves can lead to an underestimate of the calendar age range.[93] For long-life samples, having an age span of, e.g., 100 years, a moving average of the calibration data is needed and some computer programs provide this option, but extreme care obviously needs to be taken in interpreting what archaeological event such long-life samples represent. The decadal or bidecadal curves, however, are the most suitable for many of the more archaeologically appropriate radiocarbon samples such as bone and round-wood. In the absence of a recommended consensus calibration data set, currently available calibration programs use different ones, ranging from the 1986 recommended curves[94] to a combination of curves[95] largely based on those summarized in figure 12.

CALIBRATION METHODS

Like calibration data, methods of calibration are under review. A consensus is emerging, however, that calibrated dates can be faithfully represented only by probability distributions that fully take account of both the error term on the radiocarbon result and the effect of the wiggles in the curve; the wiggles indicate that any one radiocarbon result can correspond to more than one calendar age range. Unfortunately the simplest method of calibration, the "intercept method,"[96] does not properly represent those probabilities that can be calculated only with a computer program. Several such programs are available for dealing with dates individually, most of which, explicitly or implicitly, use the Bayesian methodology.[97] Their underlying model assumes *a priori* that dates on the *calendar* scale are equally probable,[98] which seems eminently reasonable in the absence of any information to the contrary. When combined with a radiocarbon result using Bayes's theorem, this model gives rise to the probability distributions produced by programs such as CAL15, CalibETH, and CALIB.[99] In contrast, those programs that "divide" radiocarbon probabilities before transferring them to the calendar scale are, in effect, assuming *a priori* that the true radiocarbon values rather than the calendar dates are equiprobable.[100]

In the interpretation of groups of radiocarbon results, the simplest approach is to use charts of confidence bars or probability distributions for the individual sample,[101] but these provide only a "by eye" indication of trends. Ideally, one should be able to combine all of the available data, both radiocarbon and archaeological, into a single statistical model. Bayesian methodology is particularly suited to this aim and can deal with, for example, calibration of a single result combined with an archaeological or historical terminus (post or ante quem), or calibration of groups of dates with stratigraphic ordering or phasing.[102] The end product consists of, i.a., probability distributions similar to those already

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[93] M. Stuiver, "A Note on Single-Year Calibration of the Radiocarbon Time Scale, AD 1510–1954," *Radiocarbon* 35 (1993) 67–72.

[94] J. van der Plicht and W.G. Mook, "The Groningen Radiocarbon Calibration Program," *Radiocarbon* 35 (1993) 231–37. T.R. Nicklaus, G. Bonani, M. Simonius, M. Suter, and W. Wölfli, "CalibETH: An Interactive Computer Program for the Calibration of Radiocarbon Dates," *Radiocarbon* 34 (1992) 483–92.

[95] Stuiver and Reimer (supra n. 90) 215–30.

[96] E.g., G. Pearson, "How to Cope with Calibration," *Antiquity* 61 (1987) 98–103.

[97] Pioneered in radiocarbon dating by J.C. Naylor and A.F.M. Smith, "An Archaeological Inference Problem," *Journal of the American Statistical Association* 83:403 (1988) 588–95.

[98] Discussed by H. Dehling and J. van der Plicht, "Statistical Problems in Calibrating Radiocarbon Dates," *Radiocarbon* 35 (1993) 239–44.

[99] Van der Plicht and Mook (CAL15) and Nicklaus et al. (CalibETH) (supra n. 94); Stuiver and Reimer (supra n. 90) 215–30.

[100] In such programs, the probability (p) associated with a given radiocarbon result is divided by the number (n) of calendar dates corresponding to that result before converting to the calendar scale. By contrast, programs that do not divide probabilities assign the whole probability (p) to *each* of the n calendar dates. For the former programs, the accumulated probabilities on the calendar scale sum to unity; for the latter, they must be standardized to do so.

[101] Examples are given by J. Ambers, S. Bowman, A. Gibson, and I. Kinnes, "Radiocarbon Results for the British Beakers," *Radiocarbon* 34 (1992) 916–27.

[102] Several examples illustrating the types of problem with which Bayesian methods can deal are described by C.E. Buck, J. Kenworthy, C.D. Litton, and A.F.M. Smith, "Combining Archaeological and Radiocarbon Information: A Bayesian Approach to Calibration," *Antiquity* 65 (1991) 808–21; also see C.E. Buck, C.D. Litton, and A.F.M. Smith,

familiar from many calibration programs, but incorporating any additional chronological information available. Bayesian methodology also allows a variety of other inferences to be made (e.g., derivation of time spans).

What are the practical implications of this type of approach for the archaeologist? Sets of results relating to the same event and shown to be contemporary can, generally speaking, be dealt with using existing calibration programs. Extending the Bayesian approach to dates relating to several events, linked stratigraphically or otherwise, however, requires more complex analysis. The mathematical formulation of the problem is not straightforward and its solution requires extensive computing resources. At present, the necessary software is not widely available, but with recent improvements in numerical methods, it will probably become more accessible. The crucial contribution of the archaeologist to the model-building process is to define the *a priori* information that links the samples, such as the stratigraphic relationships, information from historical texts, or, perhaps more controversially, hypotheses about the likely scale of activity and how it changes within and between phases.

Whether or not calibration is based on Bayesian methodology, the broad principles outlined above highlight why the sampling strategy adopted by the archaeologist is of fundamental importance, requiring consideration throughout the calibration and interpretation process. In assessing possible sampling strategies prior to submission for dating, simulation can often be of assistance. By calibrating feasible results and errors based on educated guesswork, it is possible to judge the likely success of the strategy, and indeed of radiocarbon dating, in resolving the chronological problem. The sampling strategy will determine the chronological models that can be considered and vice versa. For example, models that incorporate hypotheses about changing activity levels at a site depend on having a reasonably large set of samples selected independently and at random throughout the period under study. The outcome of the radiocarbon measurement, of course, may lead to reevaluation of the original model. Thus, for example, a strategy aimed at dating a single event through multiple samples may nevertheless produce non-contemporaneous radiocarbon results. It may be valid in specific circumstances to combine the individual calibrated probability distributions,[103] but it is perhaps more likely that the sample-context-event association has not been fully understood and needs to be reassessed.

CONCLUSIONS

Like any dating technique, the use of radiocarbon requires care in sample selection and measurement. Radiocarbon dating, however, has special problems in interpretation, because of the need for calibration. The continually growing body of calibration data and the variety of statistical models used to deal with the calibration process are daunting to assimilate. These factors, however, underline the value of early and continued collaboration among archaeologists, radiocarbon scientists, and statisticians. Only through such cooperation can the potential of Bayesian analysis be realized, a technique that holds considerable promise because of its generality and its ability to incorporate archaeological data explicitly.

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Radiocarbon Dating by Accelerator Mass Spectrometry

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The technique of measuring radiocarbon using Accelerator Mass Spectrometry (AMS) has been in existence for nearly 15 years, and radiocarbon dates have been produced by this method for over a decade. Although only about a quarter of these are archaeological, I estimate that well over 10,000 AMS archaeological dates have been produced. This short review attempts to draw some very general trends and conclusions from such abundance. I apologize in advance for drawing so frequently on the expe-

"Calibration of Radiocarbon Results Pertaining to Related Archaeological Events," *Journal of Archaeological Science* 19 (1992) 497–512.

[103] E.g., CALIB and CAL15 (supra ns. 90, 94, and 99) provide an option that simply sums calibrated probability distributions for "related" samples. While not explicitly stated, such a procedure seems to be based on the assumption that a single event has been dated by a number of samples, each of which, while not contemporary, is equally likely to represent that event.

rience of the Oxford Laboratory, but I know its work best, it has published the most archaeological dates, and it is the most specialized of the AMS laboratories in archaeological dating.[104]

THE BASIS AND SIGNIFICANCE OF THE AMS TECHNIQUE

To obtain a radiocarbon date, it is necessary and sufficient to measure the relative abundance of the carbon isotopes ^{12}C, ^{13}C, and ^{14}C in a suitable sample. The measurements must have an accuracy approaching 0.5% to hope to achieve a dating accuracy of 50 years. The main difficulty is the extremely small amount of ^{14}C, which is therefore hard to detect, and especially so in the quantities necessary to give the statistical precision required for an accurate date. The "conventional" method detects ^{14}C from its own radioactivity, but since it has a half-life of 5,730 years, only a tiny fraction of ^{14}C atoms is detected in a reasonable time, and even samples containing as much as 1 g of carbon are barely sufficient for a measurement. This sets a limit of sample size, and thereby of sample selection and sample chemical treatment procedures. The AMS method detects ^{14}C atoms independently of whether they radioactively disintegrate, measuring about 1% of all ^{14}C atoms and requiring samples of only 1 mg of carbon (and often less).

The main outcome is that archaeologists now have far more possibilities as to what samples can be dated. Therefore, the value of the technique depends very much on how well this choice is exercised. In other respects, the AMS method does not differ greatly from the conventional method. The cost is somewhat higher, the measurement error similar (though the results are more reliable due to better selection), and the age range much the same (though again, older dates are undoubtedly more reliable because samples have been better freed from modern contamination). Both methods are subject to calibration.[105] Making samples smaller by 1,000 times, however, broadens the scope for many new approaches.

ADVANTAGES OF GREATER SELECTIVITY

The advantages of much greater selectivity generally fall into two categories: an increase in the archaeological reliability of the date (nos. 1–4), and the generation of new chronological information (nos. 5–6).

1) *Rechecking dates.* If a laboratory date seems questionable, for whatever reason, sufficient sample is often available for a second measurement, which might help to confirm that the original measurement was not in error. Notoriously problematical dates, e.g., those of the Theran volcanic eruption[106] and the (Pleistocene) "Red Lady of Paviland,"[107] can thus be checked.

2) *Improved chemical "pre-treatment."* When only 1 mg of carbon is required for analysis, it is relatively easy to find material that can be better chemically characterized and/or be subjected to more stringent chemical procedures. Therefore, reasonably well preserved bone has turned out to be the sample material of preference, because it contains the chemically well defined protein collagen.[108] Poorly preserved bone, all too frequent on hot and arid sites,[109] remains problematic. The question of chemical treatment becomes especially important for dates beyond 30,000 years, and only consistent stratigraphic sequences can demonstrate its effectiveness.

3) *Comparison of different fractions.* Related to the above is the ability to compare *different* fractions (chemical or otherwise) from the same sample. Different sources of carbon in sediments can be sorted out using this approach. Of particular interest has been the comparison of the "charcoal" and "humic" fractions in charred carbonaceous material.[110] Their agreement obviously strengthens the reliability of the date obtained. This approach has been used in several situations, including the rather controversial issue of contamination in the Theran seed material. In many ways, it is one of the most powerful methods available for establishing reliability, although, of course, the cost of dating is thereby increased.

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[104] I would like to thank all the members of the Oxford Radiocarbon Accelerator Unit for their enthusiasm and support, and in particular Rupert Housley for reading a draft of this review. The Unit is partially supported by the Science and Engineering Research Council. *Archaeometry* Datelists 1–16 appear in *Archaeometry* 26–34 (1984–1992).

[105] M. Stuiver, A. Long, and R.S. Kra eds., "Calibration 1993," *Radiocarbon* 35:1 (1993).

[106] R.A. Housley, R.E.M. Hedges, I.A. Law, and C.R. Bronk, "Radiocarbon Dating by AMS of the Destruction of Akrotiri," in D.A. Hardy and A.C. Renfrew eds., *Thera and the Aegean World* III (London 1990) 207–15.

[107] R.E.M. Hedges, R.A. Housley, I.A. Law, and C.R. Bronk, "Radiocarbon Dates from the Oxford AMS System," *Archaeometry* Datelist 9, *Archaeometry* 31 (1989) 207–34.

[108] R.E.M. Hedges and G.J. van Klinken, "A Review of Current Approaches in the Pre-treatment of Bone for Radiocarbon Dating by AMS," *Radiocarbon* 34 (1992) 279–91.

[109] S. Weiner and O. Bar-Yosef, "States of Preservation of Bones from Prehistoric Sites in the Near East: A Survey," *JAS* 17 (1990) 187–96.

[110] R.J. Batten, C.R. Bronk, R. Gillespie, J.A.J. Gowlett, R.E.M. Hedges, and C. Perry, "A Review of the Operation of the Oxford Radiocarbon Accelerator Unit," *Radiocarbon* 28:2A (1986) 177–85.

A useful spin-off is that more is learned at the same time about the processes of environmental contamination.

4) *Selecting more directly relevant material.* Small charcoal samples generally enable short-term growth material to be selected, avoiding mistakes due to reuse, or differences between heartwood growth and felling times. On the other hand, small charcoal fragments (or seeds) are fragile and all too mobile, and can be used only with great caution to date the strata from which they have been excavated. The dating of the late Upper Palaeolithic (Tjongerian) site of Rekem (Belgium), whose sandy deposits contained charcoal fragments loosely associated with fires, as well as microliths (one with attached arrow shaft adhesive), is an interesting case. The charcoal dates all proved to be stratigraphically incoherent and archaeologically useless, while the adhesive was able to supply a clear and useful date.[111] In general, larger samples (e.g., bone) are found to be stratigraphically more static. We have found that finely disseminated charcoal, often collected into sedimentary lenses, is an especially difficult sample material from which to obtain consistent dates. For the dating of sediments, preserved terrestrial macrofossils are of increasing importance in establishing the regional and ecological context of an archaeological site.[112]

5) *New or better datings.* Since AMS enables more samples to be dated, despite smaller sample size, many sites can be dated, either *de novo*, or else much more thoroughly than before. This is arguably the category with the greatest general benefit to archaeological dating. In particular, open sites with limited stratigraphy, such as the French Upper Palaeolithic sites of Pincevent, Etiolles, and Marsangy, have been able to be dated. One site that has benefitted from a sustained and intensive AMS dating program is Abu Hureyra in Syria, which was occupied during the Epipalaeolithic and Neolithic periods.[113] The dating of the stratigraphy, as well as specific seeds and burnt animal bones, has helped greatly in piecing together the evidence for the development of early agriculture. Jeitun in Turkestan,[114] for which the only material available for dating was carbonized seeds, is another example of an early agricultural site that could be dated by AMS.

6) *Directly datable samples.* Many archaeological finds are precious, due to their inherent information content. Often they may still be dated by AMS if a small sample can be taken. Another dimension is thus added to the chronological framework inferred for the sample's archaeological context. As one clear example, direct dating by AMS has shown that many human inhumations (in caves, for instance) are intrusive, and of later date than the cultural remains, which are often stratigraphically indistinguishable.

In general, the more information attached to the sample, the better. For example, dating a snowshoe hare bone bearing cut-marks not only dates the depositional stratum, but also dates a human presence, and the dating refers both to human cultural practice and also to the ecological and climatic setting. Typically about 200 mg of bone is sufficient for such a date. Evidence for animal domestication or changes in plant morphology due to cultivation may also be directly dated through measuring a single charred seed or a pig tooth. Such dates, however, can turn out to be later than expected because of problems of sample movement and stratigraphic uncertainty. We have dated two grape pips found on different Neolithic sites. One was from the excavators' lunch, and the other is the first occurrence of *Vitis vinifera* in Great Britain.

One of the most important information-bearing artifactual materials in archaeology is pottery. The dating of pottery is reliable only if it contains definite traces of food residues, or if any of the original carbonaceous temper survives and can be extracted.[115] AMS dating has identified the earliest pottery so far found in the Americas,[116] and confirmed early Neolithic dates in China.

Artifacts with virtually no context have also been dated. For example, the Oxford Laboratory has dated numerous bone points and harpoons of uncertain provenience, in order to establish a general typological sequence, particularly through the Mesolithic

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[111] J.A.J. Gowlett, R.E.M. Hedges, I.A. Law, and C. Perry, "Radiocarbon Dates from the Oxford AMS System: *Archaeometry* Datelist 5," *Archaeometry* 29 (1987) 125–55.

[112] T.E. Tornqvist, A.F.M. de Jong, W.A. Oosterbaan, and K. van der Gorg, "Accurate Dating of Organic Deposits by AMS ^{14}C Measurement of Macrofossils," *Radiocarbon* 34 (1992) 566–78.

[113] A.M.T. Moore, "The Impact of Accelerator Dating at the Early Village of Abu Hureyra on the Euphrates," *Radiocarbon* 34 (1992) 850–58.

[114] R.E.M. Hedges, R.A. Housley, C.R. Bronk, and G.J. van Klinken, "Radiocarbon Dates from the Oxford AMS System: *Archaeometry* Datelist 15," *Archaeometry* 34 (1992) 337–57.

[115] R.E.M. Hedges, C. Tiemei, and R.A. Housley, "Results and Methods in the Radiocarbon Dating of Pottery," *Radiocarbon* 34 (1992) 906–11.

[116] A.C. Roosevelt, R.A. Housley, M. Imazio da Silveira, S. Maranca, and R. Johnson, "Eighth Millennium Pottery from a Prehistoric Shell Midden in the Brazilian Amazon," *Science* 254 (1991) 1621–24.

and Neolithic periods of northern Europe. More spectacular is the dating of rock paintings, which seldom contain sufficient carbon or well-characterized organic materials. Several French Upper Palaeolithic cave paintings have been dated from their charcoal content by the French AMS Laboratory at Gif.[117] More controversial is the dating of what are believed to be blood proteins from Australian rock paintings.[118] Here, reliability is again the crucial issue, for the chemical "pre-treatment" is being asked to perform at, or perhaps beyond, its limits. It is, however, an indication of the direction of future research.

CONCLUSIONS

The full archaeological potential of radiocarbon dating by AMS depends on a comprehensive grasp of how its selectivity may best be exploited. On the technical side, selectivity can be increased as smaller and smaller samples are able to be analyzed and as our understanding of the processes of organic degradation and environmental contamination improves. With deepening understanding, reliable dating beyond 50,000 years may eventually prove possible. To date, AMS's chief contributions have been to provide much greater reliability in radiocarbon dates and to forge a closer relationship between specifically archaeological information and chronological data.

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Ceramic Ecology

FREDERICK R. MATSON

Archaeologists are increasingly including consideration of ecological aspects in their studies of Near Eastern, Mediterranean, and European ceramics, but perhaps not as much as in other parts of the world. In addition to shape and decoration, long reported in detail, pottery can be examined in terms of mineral and chemical composition, variations in methods of production and firing, and, of course, stratigraphic and regional distributions. Such data, together with cautiously used knowledge of the practices of present-day village potters, can at times be of use in better understanding the social, economic, and political aspects of past cultures. The potters and the pottery they produced were insignificant in the broad cultural perspective, but the almost indestructible nature of fired ceramics, and the subtle record potsherds and vessels retain when most other material remains have long vanished, make it essential that they be carefully excavated and studied in many ways.

"Ceramic ecology may be considered as one facet of cultural ecology, that which attempts to relate the raw materials and technologies that the local potter has available to the functions in his culture of the products he fashions."[119] This characterization of the field has met with approval, and been recently discussed in some detail by Rice, who also comments on the potential value of a ceramic ecological approach in archaeological research:

> The final step of a ceramic ecological investigation is relating the accumulated data on the environmental and socio-technological factors of pottery making to the broader role of pottery in a culture. This includes such features as economic organization (local and long-distance trade arrangements), kinship structure, settlement patterns, demographic factors, ceremonial or ritual activities, and so forth.
>
> Pottery manufacture, like any other productive technology, represents a point where a cultural system interacts directly with the environmental system. . . . Ceramic ecology can be linked with ceramic technology to show pottery production as one of the many patterned ways of exploiting particular environments and as one of a variety of economic adjustments in a network of productive relations in a society. Ceramic ecology emphasizes the potter's role

[117] H. Valladas, H. Cachier, P. Maurice, F. Bernaldo de Quiros, J. Clottes, V.C. Valdés, P. Uzquiano, and M. Arnold, "Direct Radiocarbon Dates for Prehistoric Paintings at the Altamira," *Nature* 357 (1992) 68.

[118] T.H. Loy, R. Jones, D.E. Nelson, B. Meehan, J. Vogel, J. Southon, and R. Cosgrove, "Accelerator Radiocarbon Dating of Human Blood Proteins in Pigments from Late Pleistocene Art Sites in Australia," *Antiquity* 64 (1990) 110–16.

[119] F.R. Matson, "Ceramic Ecology: An Approach to the Study of Early Cultures of the Near East," in F.R. Matson ed., *Ceramics and Man* (Chicago 1965) 203–17.

> as an active and controlling agent in the procedures of pottery manufacture (resource selection, forming techniques, firing strategies) as these are revealed through technological analyses of both ancient and modern pottery.[120]

Publications on ceramic ecology are scattered widely in the literature, and few of them until recently have dealt with Old World pottery. This may be because many archaeologists interested in the subject have an anthropological background that has been more directed toward New World studies. The range of non-Old World studies that appear in the materials cited here should provide a basis for selective approaches that can be applied anywhere in the world.

A volume edited by van der Leeuw and Pritchard contains several papers related to Near Eastern ceramic ecology. In their preface, they state: "The conference which resulted in this volume . . . held in 1982 . . . was deliberately planned as a sequel to an earlier symposium entitled 'Ceramics and Man' in 1962. . . . The primary aim of the 1982 conference was to attempt to elicit an assessment of what had been achieved in the field of ceramic research since 1962, both in archaeology and anthropology, and also to suggest new directions for further research."[121] Ceramic ecology has been the topic of at least four symposia at successive annual meetings of the American Anthropological Association from 1986 through 1989, and the papers presented at the first three have been published.[122] New World ceramics are highlighted in these publications. Technological studies of Old World ceramics in their social contexts, however, appear frequently in the five volumes published between 1986 and 1990 by the American Ceramic Society in the series *Ceramics and Civilization*, edited by W.D. Kingery and P.E. McGovern. Ceramic technology was the general subject of an entire issue of *World Archaeology* (vol. 21:1, 1989). Many of the papers in this issue are pertinent for the Old World, specifically Near Eastern ceramic ecological studies. *Art and Archaeology Technical Abstracts*, which are now published by the Getty Conservation Institute, often include abstracts of ceramic research in which one or more aspects of an ecological approach appear.

Examples of ceramic ecological concerns dealing with the Near Eastern and Mediterranean regions can be subsumed under the following topics, to which others might well be added.

ENVIRONMENT

J.N. Postgate makes specific use of the voluminous historical records found on cuneiform tablets in discussing Mesopotamia from 3000 to 1500 B.C.[123] His discussions help to place potters in their ecosystem, and aid in the more effective initial study of the raw materials that the potters had available and of the markets that they supplied. Similarly, in synthesizing the archaeological evidence for the early cultures of western Iran, Hole and his colleagues relied on a detailed knowledge of the landscape and of the excavated pottery and architectural remains; in the final chapter of the book, G.A. Johnson provides an excellent example of the selective synthesis of field data to delineate a broad picture of change, including developments in ceramic production.[124] This is a far different approach from the disdainful or perhaps puckish characterization of abundant potsherds on Near Eastern sites as "fairly durable rubbish," which was made by a distinguished anthropologist over 50 years ago.

TECHNOLOGICAL STUDIES

Detailed laboratory analyses of ceramics are welcome and necessary aspects of archaeological reports, but their results too seldom are integrated into substantive discussions. Several well-illustrated reports on the Scarlet ware of the Early Dynastic period found at Uch Tepe in the Hamrin Basin of the Upper Diyala River in northeastern Iraq show, in addition to the technological data presented, a knowledge of the social or cultural aspects of the problems.[125] Results from the several analytical techniques used, while complementing one another, also provide unique perspectives on the pottery together with the cultural and natural landscape in which it was produced. As an example of a very different approach, abundant kiln wasters and finished ceramic ware were found and carefully documented at Tell Leilan in northeastern Syria, an important urban center dur-

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[120] P.M. Rice, *Pottery Analysis: A Sourcebook* (Chicago 1987) 314–17, passage quoted from p. 317.

[121] S.E. van der Leeuw and A.C. Pritchard eds., *The Many Dimensions of Pottery: Ceramics in Archaeology and Anthropology* (Amsterdam 1984) xv.

[122] C.C. Kolb and L.M. Lackey eds., *A Pot for All Reasons: Ceramic Ecology Revisited 1987: The Technology and Socioeconomics of Pottery* (*BAR-IS* 346, Oxford 1988); Kolb ed., *Ceramic Ecology, 1988: Current Research on Ceramic Materials* (*BAR-IS* 513, Oxford 1989).

[123] J.N. Postgate, *Early Mesopotamia: Society and Economy at the Dawn of History* (London 1991).

[124] G.A. Johnson, "The Changing Organization of Uruk Administration on the Susiana Plain," in F. Hole ed., *The Archaeology of Western Iran: Settlement and Society from Prehistory to the Islamic Conquest* (Washington, D.C. 1987) 107–39.

[125] M. Gibson ed., *Uch Tepe* II: *Technical Reports* (Chicago 1990).

ing the third millennium B.C. On the basis of compositional analyses and measurements of the vessel dimensions, together with statistical studies using several indices of standardization, it was shown that, with careful spatial and chronological controls, "one can use the standardization hypothesis as an effective methodology in reconstructing the productive organization of complex societies."[126]

CERAMICALLY DEFINED CULTURES

A sampling of recent publications concerned with ecological aspects of ceramics indicates, to some extent, the wide range of existing interests. The 'Ubaid period in lowland Mesopotamia with its well-known ceramics is the connecting link in time between the earliest farming communities and the more complex, regionally organized societies of the Uruk period, which were the forerunners of the Sumerian city-states. A recently published group of papers on the 'Ubaid[127] relies greatly on the ceramic evidence in discussing trade and incipient state formation. One diagnostic vessel type of the Uruk period is the bevel rim bowl, which occurs in great abundance at many sites. There are many suggestions concerning the use of these bowls, but few that are convincing. Is it possible that the bowls were used to lightly bake bread, which in turn was used in the production of beer, a staple food product? Chazan and Lehner make a cogent argument for this hypothesis, summarizing previous studies and citing pottery parallels, especially as illustrated in tomb drawings in Egypt.[128]

The pottery of medieval Nubia has been thoroughly studed by Adams,[129] who discusses the detailed information he has obtained from both archaeological and ethnographic materials. The trade of widely distributed Egyptian water jars, made for the most part at Ballas in Upper Egypt, is one facet of a detailed study of pottery manufacture at this site.[130]

The ecological aspects of the early phases of Neolithic ceramic production in the Aegean world are briefly considered in Vitelli's exceptionally thorough report[131] on the pottery excavated at Franchthi Cave in southeastern Greece. In her concluding chapters, she comments on cooking pots that were probably used for other purposes, specialist potters who produced Urfirnis ware, potters who may have been shamans, and pots as markers of social change.

CERAMIC ETHNOARCHAEOLOGY

Kramer's thorough survey and discussion of ceramic ethnoarchaeology[132] focuses on studies "which explicitly consider contemporary pots and potters in terms of particular problems with which archaeologists frequently struggle." Her discussions of ceramic production, use, disposal, and change help place Near Eastern pottery studies in a world perspective, broadening the range of possible areas of ceramic inquiry for the Near East and the Mediterranean regions. Longacre's broad-ranging compilation of papers from an advanced seminar at the School of American Research in 1985 includes only one article that pertains to our present areas of discussion.[133] His authors, all archaeologists, concern themselves with identifying social and behavioral sources of ceramic variation in societies all over the world. The bibliography in this volume is exceptionally thorough.

Village potters in Pakistan, and until recently in Afghanistan, continue to produce their wares unimpeded by modern technical practices. They provide current examples of long-standing techniques of pottery making. Rye and Evans's detailed report on Pakistani pottery[134] is exceptionally well illustrated and documented, and includes analytical results from laboratory studies.

Theoretical considerations, as well as field documentation, have great merit. The way in which Arnold[135] organizes the ceramic data obtained from

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[126] M.J. Blackman, G.J. Stein, and P.B. Vandiver, "The Standardization Hypothesis and Ceramic Mass Production: Technological, Compositional, and Metric Indexes of Craft Specialization at Tell Leilan, Syria," *AmerAnt* 58 (1993) 77.

[127] E.F. Henrickson and I. Thuesen eds., *Upon This Foundation: The 'Ubaid Reconsidered* (Copenhagen 1989).

[128] M. Chazan and M. Lehner, "An Ancient Analogy: Pot Baked Bread in Ancient Egypt and Mesopotamia," *Paléorient* 16 (1990) 21–35.

[129] W.Y. Adams, "The Social and Economic Background of Nubian Pottery Manufacture," in W.Y. Adams, *Ceramic Industries of Medieval Nubia* (Lexington, Ky. 1986) 34–35.

[130] P.T. Nicholson and H.L. Patterson, "The Ballas Pottery Project: Ethnoarchaeology in Upper Egypt," in G.J. Bey III and C.A. Pool eds., *Ceramic Production and Distribution* (Boulder 1992) 25–47.

[131] K.D. Vitelli, *Franchthi Neolithic Pottery* 1: *Classification and Ceramic Phases 1 and 2* (Bloomington 1993).

[132] C. Kramer, "Ceramic Ethnoarchaeology," *Annual Review of Archaeology* 14 (1985) 77–102.

[133] C. Kramer, "Ceramics in Two Indian Cities," in W.A. Longacre ed., *Ceramic Ethnoarchaeology* (Tucson 1991) 205–30.

[134] O.S. Rye and C. Evans, *Traditional Pottery Techniques of Pakistan: Field and Laboratory Studies* (Smithsonian Contributions to Anthropology 21, Washington, D.C. 1976).

[135] D.E. Arnold, *Ceramic Theory and Cultural Process* (Cambridge 1985).

his own fieldwork in Mexico, Guatemala, and Peru, together with that culled from ethnographic and archaeological reports, leads to generalizations and theorizing about the massive literature on ethnographic ceramics. Arnold is also concerned with what stimulates or hinders ceramic production. The relatively few Near Eastern entries in his index suggest that there is still much left to be done with Near Eastern ceramics in this regard.

As a final note, since archaeological fieldwork is not possible at present or severely limited in many parts of the Old World, it may well be the time to reconsider from an ecological point of view the pottery that is available in museums and extensively reported upon in publications. Materials now in storage or on exhibit might be reexamined. Questions could then be posed that supplementary fieldwork might be able to answer when excavation and site surveying resume on a larger scale.

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Ceramic Petrography

IAN C. FREESTONE

The petrography of archaeological ceramics involves the description, classification, and interpretation of ceramic pastes, or fabrics, using techniques derived from those used in geology to describe rocks (petrography).[136] The primary research tool is the petrographic, or polarizing, microscope, and the ceramics are examined as thin sections, prepared from slices or fragments of pottery that are fixed to glass slides and abraded to a standard thickness (0.03 mm). At this thickness, many of the more common minerals become translucent, and may be identified on the basis of their characteristic optical properties, such as color, refractive index, and cleavage (fracture pattern).

In ceramic petrography, attention is focused primarily upon the identification of the nonplastic inclusions that are set in the fine-grained clay matrix, as well as the determination of their textural characteristics such as abundance, shape, and size. The inclusions are typically defined as those inclusions of the paste that may be characterized effectively—in practice, those that are larger than the 0.03 mm thickness of the section. These are most commonly rock or mineral fragments, ranging up to several millimeters in diameter and occupying a large volumetric percentage of the fabric. Inclusions may occur naturally in the clay, in which case they are described as "intrinsic" or "incidental." Alternatively, they may have been added deliberately by the potter to improve the working or firing properties, in which case they are commonly described as "temper." In addition to materials derived from rocks, tempers may include a range of biological and man-made materials such as grog (crushed pottery), chaff, bone, slag, and shell.

Petrography is invaluable in the study of paste preparation techniques[137] and can yield useful information on methods of forming[138] and firing parameters.[139] The interest of most archaeologists, however, is in the utility of the method in the determination of provenience. In this review, provenience studies are emphasized, together with some guidelines that are of assistance for designing a successful project or in evaluating a proposed project design.

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[136] This essay has benefited from many discussions among members of the Ceramic Petrology Group. The views expressed remain my own, however. I thank Sheridan Bowman and Andrew Middleton for their comments on the draft.

A recent collection of applications and methodological papers is A. Middleton and I. Freestone, *Recent Developments in Ceramic Petrology* (*BMOP* 81, London 1991). Petrography and other mineralogical approaches to pottery are integrated together in a collection of papers edited by S. Méry, *Sciences de la terre et céramique archéologiques* (Documents et Travaux, Institut Géologique Albert de Lapparent, no. 16, Cergy 1992).

[137] See, e.g., I.C. Freestone and V. Rigby, "The Introduction of Roman Ceramic Styles and Techniques into Roman Britain: A Case Study," in E.V. Sayre et al. eds., *Materials Issues in Art and Archaeology* (Materials Research Society Symposium Proceedings 123, Pittsburgh 1988) 109–15. Also see B. Vincent, "Ceramic Technology in Thailand," *Indo-Pacific Prehistory Association Bulletin* 10 (1991) 341–48.

[138] A. Woods, "An Introductory Note on the Use of Tangential Thin Sections for Distinguishing between Wheel-Thrown and Coil/Ring-Built Vessels," *Bulletin of the Experimental Firing Group* 3 (1984/1985) 100–14.

[139] Many authors have noted changes in the optical characteristics of minerals in fired pottery. For an account of such changes, see J.C. Echallier and S. Méry, "L'évolution minéralogique et physico-chimique des pâtes calcaires au cours de la cuisson: Expérimentation en laboratoire et application archéologique," in Méry (supra n. 136) 87–120.

PROVENIENCE STUDIES

In the broadest sense, the term "provenience" is usually understood to involve the subdivision of ceramic assemblages into production-related groups, without necessarily locating the sources themselves, although this remains the ultimate goal. Petrography may be considered useful on a number of levels. First, it is invaluable in paste classification, enabling the identification of wares produced from the same raw materials in the same technological tradition, e.g., grog-tempered ware, sandy ware, etc.[140] The discrimination between likely production groups is more convincingly demonstrated using petrography than by macroscopic examination alone, and is best carried out on a carefully selected sample at an early stage in the processing of large bodies of excavated pottery. The close relationship between the observations in thin section and the appearance of a sherd in fracture allows petrographically defined paste groups to be used as standards against which the remaining bulk of the pottery may be sorted using low-power binocular microscopy. Outliers are readily identified in this way.

Second, petrography may be used in paste characterization. A detailed petrographic description may be used to fingerprint a paste, establish a paste group, and compare it with ceramics from a known source.[141] Within a relatively homogeneous geological environment, however, the differences between pastes produced at different workshops may be slight and not distinguishable qualitatively. Therefore, attempts have been made to improve the precision of petrographic descriptions by estimating the volumetric proportions of the minerals present as volume percentages (modal analysis) or by measuring the grain size distributions of the inclusions (fig. 13). These measurements can be time-consuming, but offer the possibility of applying statistical techniques to establish paste groups and discriminate between sources. In this way, petrography may be used to provenience ceramics in a manner similar to trace element analysis.[142] Nevertheless, the heterogeneous

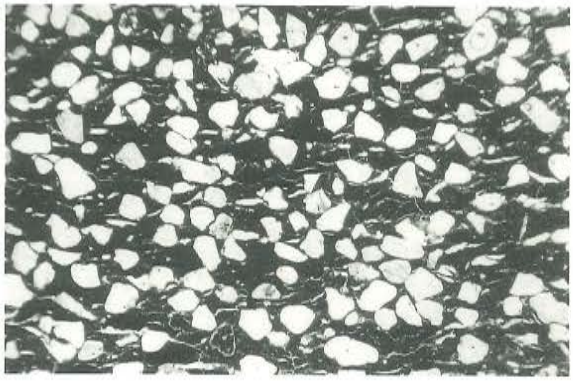

Fig. 13. Pastes containing abundant inclusions of quartz sand are unlikely to be immediately diagnostic of source. In the case of this pottery from the Iron Age site of Hengistbury Head (Dorset, southern Britain), however, it has been possible to distinguish two important production groups on the basis of grain size distribution, a distinction that has been confirmed by trace element analysis. The photomicrograph, with a field of view 6 mm across, shows abundant subangular grains of quartz (pale) in a fine-grained fired clay matrix (dark).

nature of the coarse fraction of the ceramic paste is a limitation, so that even quantitative petrographic approaches of this type lack the precision and sensitivity (hence the discriminating power) of modern elemental techniques such as neutron activation analysis (NAA) and inductively coupled plasma spectrometry (ICPS). NAA and ICPS routinely achieve a precision of about 2% on 20 or more elements. There are rarely more than three or four mineral species present in a ceramic paste that can be quantified with such a degree of precision. If paste groups cannot be distinguished by qualitative or semi-quantitative petrographic methods, then recourse to trace element analysis rather than quantitative petrography is the approach most likely to be successful.[143]

Finally, the potential of petrography as a predictive provenience technique has resulted in the widespread application of the method. The rock and mineral inclusions within a paste are a reflection of the geology of the source area of the ceramic. Therefore,

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[140] Supra n. 137.

[141] This type of approach is illustrated in many published applications; see Middleton and Freestone (supra n. 136) passim.

[142] For a discussion of some of these approaches, see I.C. Freestone, "Extending Ceramic Petrology," in Middleton and Freestone (supra n. 136) 399–410.

[143] Petrography and elemental analysis have frequently been found to show reasonable agreement when applied to the same material. See, e.g., A.P. Middleton, M.R. Cowell, and E.W. Black, "Romano-British Relief-Patterned Flue Tiles: A Study of Provenance Using Petrography and Neutron Activation Analysis," in Méry (supra n. 136) 49–60; G. Schneider and E. Wirz, "Chemical Approaches to Archaeological Questions: Roman Terracotta Lamps as Documents of Economic History," in Méry (supra n. 136) 13–48, also found the chemical classification replicated in a subset of their sample subjected to thin-section analysis. Y. Maniatis, R.E. Jones, I.K. Whitbread, A. Kostikas, A. Simopoulos, C. Karakalos, and C.K. Williams, "Punic Amphoras Found at Corinth, Greece: An Investigation of Their Origin and Technology," *JFA* 11 (1984) 205–22, find good agreement in a range of characterization techniques.

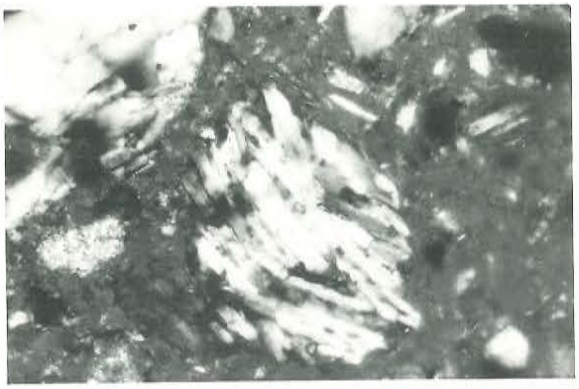

Fig. 14. Inclusions of trachytic volcanic lava (center, composed of elongate laths of feldspar) in a first-century B.C.–first-century A.D. flagon, found in Braughing, Hertfordshire, clearly suggest a nonlocal origin. Associated fragments of granite and metamorphic schist (not shown) suggest a source in the ancient volcanic area of the Massif Central, France, rather than Italy, where the three rock types are not commonly juxtaposed. Field of view = 3 mm.

it may be possible to predict the geology of the source area from the ceramic petrography and, from a knowledge of the regional geology, predict the location of the source. In some circumstances, only a single thin section may be needed to make such a prediction, and this characteristic distinguishes petrography from other provenience techniques that depend on statistical matching with reference groups based upon the analysis of large numbers of samples. There are many classic examples of this type of study.[144] It is particularly successful when the ceramic raw materials have been obtained from a localized outcrop of rocks of unusual composition, such as from an igneous intrusion or a metamorphic inlier surrounded by sedimentary rocks (fig. 14). Unfortunately, successes are outweighed by failures. It is typically not possible to predict the source location when the geologies of the source area and the findspot are similar, when the paste is fine-grained, or when the prevailing ceramic technology is dominated by the use of an undiagnostic temper type, such as grog or organic material. For this reason, it is desirable to understand the constraints that act upon the petrographic method before embarking upon a research program.

PETROGRAPHIC RESOLUTION

The success of a project is in general determined by what may be termed the resolution of the petrographic technique—viz., the degree to which the petrographies of the ceramics under study allow discrimination between production groups or potential raw material sources.[145] The petrographic resolution can vary greatly, depending on a number of factors that are discussed below. An awareness of these factors not only enables the evaluation of the likely success of a proposed research program, but also facilitates good project design. The geographical limits of a postulated source area also depend on a number of these factors and are closely related to the petrographic resolution.

1) *The geology of the study area.* The more variable and diverse, the more likely are production groups to have qualitatively different fabrics. Of course, the geology is likely to be more diverse on an international scale than a local one, which is reflected in the success of the technique in identifying interregional movement in some ceramics, such as Roman transport amphoras.

2) *A well-characterized data base.* A good background knowledge of the petrographies of other ceramic types from the region and period as well as of the local geology (backed up by fieldwork and sampling of potential raw materials, particularly where maps, memoirs, and reference collections are not comprehensive) can be of great value in improving the petrographic resolution so that useful conclusions may be made even in relatively unpromising situations.[146]

3) *Ceramic technology.* In general, pastes with coarse rock and polymineralic sand tempers are more likely to provide evidence of the source geology than are very fine-grained pastes.[147] There are, however, some outstanding examples of fine-grained pastes that are highly diagnostic of source. For example, certain fine

[144] The studies of Peacock have been notably successful. See D.P.S. Peacock, "A Contribution to the Study of Glastonbury Ware from South-Western England," *AntJ* 49 (1969) 41–61; D.P.S. Peacock and D.F. Williams, *Amphorae and the Roman Economy* (London 1986); M.G. Fulford and D.P.S. Peacock, *Excavations at Carthage: The British Mission* 1, pt. 1 (Sheffield 1984).

[145] The term resolution is used here in a slightly different sense than that suggested by P.A. Wardle, *Bronze Age Pottery from Eastern Yorkshire* (Diss. Univ. of Bradford 1991), who uses it to indicate the geological limits, expressed in kilometers, for locating a pottery source.

[146] See, e.g., T. Kilka, "An Example of Study Where the Petrography Prevails over the Chemistry: The Bronze Age Ceramics from Fiave (Italy)," in Méry (supra n. 136) 61–72. Also see W.K. Barnett, "The Identification of Clay Collection and Modification in Prehistoric Potting at the Early Neolithic Site of Balma Margineda, Andora," in Middleton and Freestone (supra n. 136) 17–38.

[147] The traditional view that, in contrast to fine wares, coarse pots were not widely traded has been overturned to a large extent. Analytical studies demonstrate that cooking pots, for example, sometimes move over long distances.

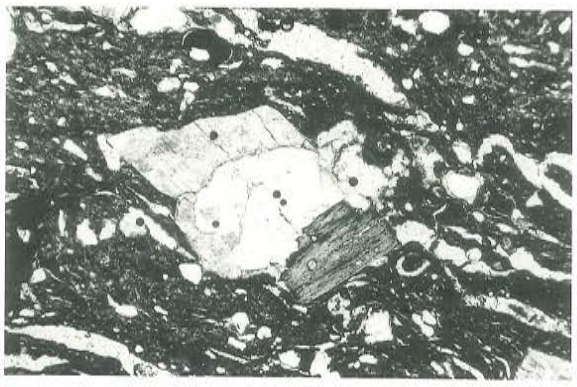

Fig. 15. Angular fragments of granite temper in this Late Bronze Age pot from Yorkshire might suggest a foreign origin, as the local geology is sedimentary, but they, in fact, represent the preferential utilization of hard pebbles and boulders from glacial drift in the area as temper. The photomicrograph shows a central fragment of granite containing three minerals: feldspar (cloudy), quartz (white), and biotite mica (dark, striated). Field of view = 6 mm.

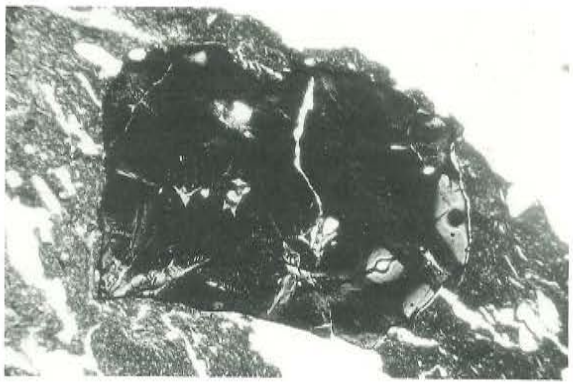

Fig. 16. Slag temper in Iron Age ceramic sample from Timna, a Bronze Age copper-smelting site in the Negev of Israel. The local geology is not particularly promising for provenience studies, but the choice of slag temper clearly supports local production. Field of view = 3 mm.

wares produced in southern Italy in the Hellenistic and Roman periods are characterized by the presence of numerous very fine fragments of volcanic glass in the matrix. It is essential that the analyst take full advantage of the information offered by the petrography to understand the ceramic technology, since pottery-making traditions can mislead the analyst (for example, the potter might have mixed clays or used as temper pieces of erratic boulders that had traveled far; see fig. 15).

4) *Petrological interpretation.* Experience has shown that a good understanding of the modes of formation and occurrence of rocks can be very significant in interpreting the ceramic petrographies of pots. For example, the compositions of certain relatively common mineral types, such as feldspars, reflect the geological environment from which they are derived, whether plutonic, metamorphic, or volcanic. The term "ceramic petrology" is sometimes used to describe the broader theoretical framework of this approach. The implication is that the analyst possesses or has access to a level of interpretative skill beyond the purely descriptive.[148]

5) *Reducing background "noise."* By comparing like with like and restricting the sample to ceramics that have been closely defined in terms of typology, better petrographic results can be achieved. Many of the most successful provenience studies have been based on carefully restricted ceramic types, such as "Glastonbury Ware," "Pompeian Red Ware," etc.

6) *A sufficient sample size.* Where the differences between paste groups are subtle or not immediately apparent, it is often essential that multiple examples of each group are represented in the analytical sample. The worst type of sample upon which to base a petrographic study is a selection of 40 or 50 sherds, each of which represents a different ceramic type or form. Where groups are established on the basis of statistical analysis of quantitative data, then the minimum size of a group to ensure that it is valid may well be 10 or more.

It will be recognized that the degree of resolution required for the successful outcome of a project depends upon the questions to be answered. To the archaeologist working in prehistoric Britain or France, the identification of a volcanic sand in a ceramic paste is very significant, pointing to an origin in southern Italy. To the excavator of a villa in the vicinity of Rome or Naples, such information is often of no assistance as volcanic sands are ubiquitous there. Thus, in project formulation, it is necessary to balance the resolution anticipated on the basis of geology, ceramic technology, and the available number of samples against that required to answer the questions of interest.

Even when all other controlling factors appear favorable, pottery traditions can be critical in determining the extent to which petrography is useful (fig. 16). If calcined bone or some other widely available material was used to temper a clay, then there may be no possibility of proveniencing a ware, even if production took place over the outcrop of a unique

[148] An outstanding illustration of the relationship between ceramic petrography and geological environment is given by W.R. Dickinson and R. Shutler, "Petrography of Pacific Islands Potsherds," summary in *Geological Society of America Bulletin*, pt. 1, 90 (1979) 993–95, with the full paper in part 2 of the same journal, 90 (1979) 1644–1701 (microfiche only).

rock type. For this reason, a pilot study of up to 20 thin sections is always to be recommended before any major piece of work is undertaken. An informed judgment of the likely outcome can then be made, and the optimal sample can be selected.

CONCLUSIONS

With an appreciation for the factors that influence a petrographic project, a researcher should be able to make a realistic assessment of the potential of an analytical program in his/her problem area and the levels of interpretation that are possible. Projects may be structured so that, if direct provenience prediction is not possible, then useful information will be obtained at the level of paste classification or characterization. The petrographic resolution may be improved by systematic collection of reference materials, including geological data, raw material samples and comparative ceramics from the study area. Pilot studies may be carried out on selected groups of material. Finally, it should be emphasized that an experienced analyst is best fitted to advise on and carry out a project if he/she is involved in research formulation at as early a stage as possible.

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Ceramic Petrology and Petrography in the Aegean

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INTRODUCTION

Ceramic petrological and petrographic techniques, which are derived from the geological sciences, have proved to be valuable tools for both the characterization and proveniencing of ancient pottery and other ceramics (including building materials such as concrete, mortar, plaster, etc.). Petrology is broadly defined as the study of rocks according to their chemical, physical, and optical attributes, to elucidate their occurrence, mineralogy, structure, origins, history, and interrelationships. It involves considerable fieldwork in mapping and sampling rock formations in a given region, so that potential source deposits and quarries used in antiquity can be characterized. Petrography is more narrowly defined (see the preceding section by I.C. Freestone), and involves the systematic study of geological *and* archaeological samples by describing and interpreting their rock and mineral composiiton and texture in hand specimens and, especially, in thin sections.[149]

HISTORICAL OVERVIEW

The original thrust of petrographic techniques, as they evolved in the 19th century, was the assemblage of sufficiently detailed information to classify rock types and their constituent minerals. One of the earliest applications of petrography to archaeological materials was undertaken by G.R. Lepsius,[150] who characterized the marbles of museum artifacts and major quarries of the classical period. The problem of mineralogical variation within single quarries was not addressed in this early work, however, and the selective use of one or two of Lepsius's petrographic characteristics by later art historians led to what appeared to be overlapping source attributions. This in turn led to dissatisfaction with the technique.

The pioneering work of 19th-century scientists went largely unappreciated by archaeologists, who were working out artifact typologies based primarily on stylistic criteria. Indeed, up until the last 25 years, relatively few petrological and petrographic studies of ancient Aegean materials had been carried out.[151]

As for any developing discipline, some of the early work suffered from cursory stylistic and technical descriptions of the pottery, minimal petrographic detail (which is essential for future reference), and little correlative fieldwork for meaningful interpretation of the petrographic data. For example, while her preliminary petrographic data may be fine, such limitations are evident in Pittinger's summary analyses of Cycladic pottery,[152] which also did not

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[149] See P.F. Kerr, *Optical Mineralogy*[4] (New York 1977), and C.S. Hutchison, *Laboratory Handbook of Petrographic Techniques* (New York 1974).

[150] G.R. Lepsius, *Griechische Marmorstudien* (Berlin 1890).

[151] E.g., L. Courtois, "Note préliminaire sur l'origine des différentes fabriques de la poterie du Chypriote récent," *RDAC* 1970, 81–85; M. Farnsworth, "Greek Pottery: A Mineralogical Study," *AJA* 68 (1964) 221–28; W.M. Felts, "A Petrographic Examination of Potsherds from Ancient Troy," *AJA* 46 (1942) 237–44; G. Guerreschi, "Ceramica preistorica al microscopio," *Sibrium* 8 (1966) 151–60; F.R. Matson, "Could Pottery Have Been Made at Kea?" *AJA* 71 (1967) 191 (abstract).

[152] J. Pittinger, cited as personal communication in R.E. Jones ed., *Greek and Cypriot Pottery: A Review of Scientific Studies* (Athens 1986) 263–64.

include any material benchmarks for each island's domestic ceramic fabrics against which variants could have been assessed. Underfunded and poorly conceived petrographic projects, which have not been incorporated into the archaeological research design of a site from the beginning, have also resulted in undigested, largely irrelevant appendices at the end of archaeological reports.

Despite the persistent methodological and financial problems, petrographic research on ancient Aegean pottery has seen some notable recent advances in methodology,[153] terminology,[154] ethnographic analogy,[155] experimental work in establishing agreed-upon criteria for temper identification,[156] deriving technological inferences from petrographic data,[157] and the archaeological and geological rationale of preliminary petrological and petrographic research.[158]

PRACTICAL CONSIDERATIONS

An important distinction must be kept in mind when comparing the petrographic data of stones and clays that have been collected in the field and those of ceramic artifacts. Mineral and rock inclusions in pottery can be directly altered by the potter. For example, in refining a clay by settling or sieving out relatively heavier or larger materials, respectively, or in adding temper that may have been sorted or crushed, the petrography of the pottery fabric will appear to be inconsistent with the unmodified clay of its source.

In the Aegean, modern potters using traditional methods typically mix clays, even adding in soils, to achieve certain working and firing properties for the paste. Such mixtures are notoriously difficult to distinguish in thin sections, even when the ingredients are present in known percentages. In a recent unpublished study of clays used by traditional potters on the Cycladic island of Siphnos, I made briquettes from the recipes of some of the potters. A common mixture was a dark red clay derived from the local schist and a highly altered, pale chloritic clay from weathered schist exposures, in a ratio of 2:1. Photomicrographs of the thin section of a briquette made from this mixture show a fine micaceous fabric, with no particular clue that it represents a mixture, much less any suggestion of the relative ratios of the known components.

By analogy, mixed materials in thin sections of ancient pottery are generally difficult to identify. Contrasting mineralogical features, however, can be suggestive. For example, significantly larger and more angular rock fragments of mineralogy contrasting with that in the fabric groundmass could well be the result of crushed rock temper having been added to the clay. But the analyst must be cautious. A thin section of a briquette made from a settled sample of a granodiorite clay from Naxos also contains angular, heterogeneous rock fragments, and clays derived from some formations can exhibit marked mineralogical heterogeneity, which might be misinterpreted by an analyst as evidence of materials mixed by the potter. It is important to determine the properties of the available clays near an ancient production center, since specific clays were either suitable or unsuitable in unmixed condition for making certain items (e.g., water jars, cooking pots) or using a specific manufacturing technique (such as wheel-throwing or hand-building). The decision to temper or not temper a clay reflects the potters' considerations of the material and technological properties of the available resources.

A petrographer must also be alert for other kinds of alterations in pottery sherds, such as the presence of secondary calcite deposited by groundwater during burial (frequently marked by concentric rings

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[153] Freestone (supra n. 142); R.W. Dell'mour, "Keramikanalyse mit dem Polarisationsmikroskop: Methodik, Interpretation, Beispiele," *Archaeologia austriaca* 73 (1989) 17–34.

[154] I.K. Whitbread, "The Characterisation of Argillaceous Inclusions in Ceramic Thin Sections," *Archaeometry* 28 (1986) 79–88; Whitbread, "A Proposal for the Systematic Description of Thin Sections towards the Study of Ancient Ceramic Technology," in Y. Maniatis ed., *Archaeometry: Proceedings of the 25th International Symposium* (Amsterdam 1989) 127–38.

[155] P.M. Day, "Technology and Ethnography in Petrographic Studies of Ceramics," in Maniatis (supra n. 154) 139–47.

[156] N. Cuomo di Caprio and S.J. Vaughan, "Differentiating Grog (Chamotte) from Natural Argillaceous Inclusions in Ceramic Thin Sections," *Archeomaterials* 7 (1993) 21–40.

[157] S.J. Vaughan and D. Guppy, "Statistics and the Archaeological Sample," in C.L.N. Ruggles and S.P.Q. Rahtz eds., *Computer and Quantitative Methods in Archaeology 1987* (*BAR* 393, Oxford 1988) 55–59; Vaughan, "Late Cypriot Base Ring Ware: Studies in Raw Materials and Technology," in Middleton and Freestone (supra n. 136) 337–68; S.J. Vaughan, "Material and Technical Characterization of Late Cypriot Base Ring Ware: A New Fabric Typology," in J.A. Barlow, D.R. Bolger, and B. Kling eds., *Cypriot Ceramics: Reading the Prehistoric Record* (University Museum Monograph 74, University Museum Symposium Series 2, Philadelphia 1991) 119–30.

[158] P.N. Hunt and D.R. Griffiths, "Optical Petrology in the Field," *WorldArch* 21 (1989) 165–72.

of deposition around voids), and the loss of a certain percentage and/or type of inclusion due to post-excavation treatment of the pottery (especially, acid-cleaning in Greece) or to "plucking" during the abrasive preparation of the sherds as thin sections.

The petrography of archaeological pottery can provide information on a range of technological issues. For example, firing temperatures can be estimated by the relative birefringence of clay particles and the condition of primary carbonate minerals (such as calcite) in the fabric, because temperatures over 830° C contribute to the dissociation of primary carbonates and destroy clay particle birefringence. Pottery fabrics fired as high as 1000° C, however, can contain primary carbonates, whose dissociation behavior was, in fact, governed by a number of variables, including inclusion dimension, calcite crystal size, clay matrix composition, the relative vitrification (glassiness) of the ceramic surface, and the proximity of inclusions to the surface. In thin section, one can also distinguish vessel surfaces finished by applied slips from those simply wet-smoothed, and evidence of burnishing or polishing is frequently attested by the orientation of finer particles (particularly, platey clays and micas) parallel to the object's treated surface.

The size requirements of a petrographic sample, an approximately 2-cm² sherd, which is significantly more than that required for isotopic or elemental analyses (as little as 20–200 mg), can sometimes pose a problem in obtaining permission from museum and antiquity authorities. Smaller pilot projects, with careful research designs and limited sampling, are especially valuable initially. The analyst should take care that vessels of different size and function are represented for each pottery class or ware, and that the part of each vessel that is sampled is most uniformly representative of the vessel's fabric. For example, body sherds are usually adequate for mineralogical comparisons. If the parent vessels are of different dimensions, however, the petrographic profiles of the sherds may not be comparable, since the fabric of a larger vessel often contains more inclusions, providing support for the wider, taller walls, than that of a smaller vessel.

Coarse wares are particularly amenable to petrological and petrographic research, and are important in elucidating both long-distance trade (e.g., using storage jars and pithoi) and local activities (such as employing different clay bodies for cooking and storage vessels). Fine fabrics and, most recently, more utilitarian tools and products of coarser fabrics—rooftiles, drains, bricks, basins, beehives, tuyères, crucibles, spindle whorls, etc.—have been profitably studied by petrography, providing an excellent perspective on the range of ceramic raw material exploitation within a defined geographic region. The full potential of ceramic petrology and petrography will be realized, however, only when well-conceived archaeological projects are coupled with programs of field exploration and sampling of relevant clays and geological deposits.

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Ancient Vitreous Materials

JULIAN HENDERSON

Vitreous materials, such as glass and glazes covering stones and crushed quartz (faience), have been produced deliberately or adventitiously for thousands of years, from at least as early as ca. 4000 B.C. Worked obsidian, a naturally formed glass, extends the human use of a vitreous material considerably further back in time. Vitreous means that a material is made of, derived from, or contains glass; according to scientific terminology, glass is described as a supercooled liquid whose structure is normally noncrystalline and lacks a long-range, ordered structure.[159]

Included under the heading vitreous, in addition to glass, are materials that are referred to as faience, "paste," enamel, frit, and glaze. Faience consists of both glassy and crystalline components in which the crystals are almost always silica (which occurs most

[159] W.A. Weyl and E.C. Marboe, *The Constitution of Glasses: A Dynamic Interpretation* (London 1962); R.H. Brill, "A Note on the Scientist's Definition of Glass," *JGS* 4 (1962) 127–38; J. Henderson, "Some Chemical and Physical Characteristics of Ancient Glass and the Potential of Scientific Analysis," *The Glass Circle* 7 (1991) 67–77.

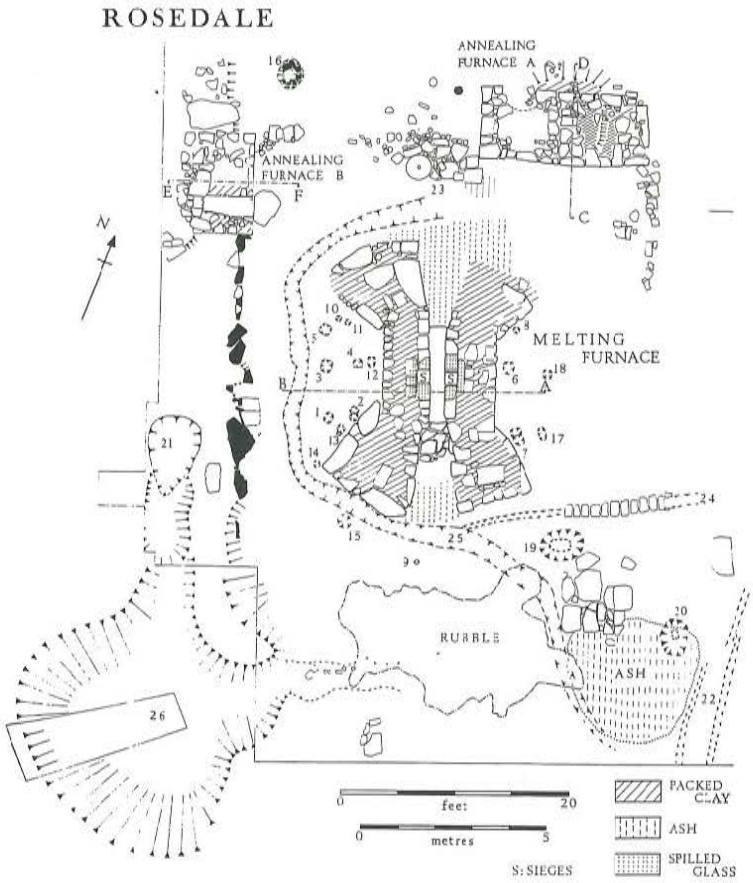

Fig. 17. Plan of an excavated 17th-century A.D. glass-melting furnace of the northern type, with separate annealing furnaces, at Rosedale, Yorkshire, England. (D.W. Crossley and F.A. Aberg, *Post-Medieval Archaeology* 6 [1972] fig. 57)

abundantly as the mineral quartz). The term "paste" is often used in technologically imprecise ways. For example, on close examination, some "paste" objects are found to be made or molded from an opaque glass, which is composed of fused particles of ground glass. Enamel, on the other hand, is clearly definable as translucent or opaque glass set into a metal or glass surface—most commonly in antiquity by cloisonné or champlevé techniques on metal. Frit is composed of the basic raw materials of glass production that are only partially fused. Again, the archaeological usage of the term "frit" can be quite ambiguous. Glazes are simply glasses applied to pottery or stone surfaces, and often contain high lead oxide levels. Their "fit" or adhesion to a surface is especially important and, as with vitreous enamels, the relative amount and rate of expansion and contraction of the glaze and substrate is critical for its structural integrity. A family of vitreous materials known as fuel-ash slags is produced accidentally as by-products of many high-temperature industries.

MANUFACTURE, RAW MATERIALS, AND PROPERTIES

Vitreous materials are produced using a range of raw materials.[160] These include silica, an alkali such as soda or potassium oxide, and a calcium-rich raw material (e.g., lime), which, when fused, form a soda-lime-silica glass. Lead oxide, mineral colorants, opacifiers, clarifiers, and opalizers are used for creating and modifying the color and physical appearance of vitreous materials. Waste glass (called cullet) is often added to the "batch" of raw materials and

[160] W.E.S. Turner, "Studies of Ancient Glass and Glass-Making Processes," parts III and V, *Journal of the Society of Glass Technology* 40 (1956) 39–52, 277–300; J. Henderson, "The Raw Materials of Early Glass Production," *OJA* 4 (1985) 267–92.

reduces the overall melting temperature; its use is therefore economically advantageous. Obviously, quite specific temperature regimes are necessary to melt or sinter raw materials (the latter involves heating the raw materials below their melting points until they form a solid mass), as well as to recycle glass, apply enamels and glazes effectively, anneal glass and glazes (i.e., reheat them following manufacture, in order to allow them to "relax" or stabilize), manufacture faience, and develop or retain color and opacity/clarity in vitreous materials. Furnaces and kilns were designed quite specifically in keeping with the close control of temperatures demanded by the industrial processes. For example, one principal glass-melting furnace type (the so-called southern type) is comprised of a stoke hole, melting chamber, and lower-temperature annealing oven as separate chambers of a single construction, whereas the so-called northern type has an annealing oven that is separate from the main furnace (fig. 17).

Lower temperatures were also involved in fritting glass raw materials—that is, partially melting primary raw materials and removing any impurities—than for full fusion, and such operations were sometimes carried out in special furnaces. Experimenting with a range of manufacturing techniques and conditions reveals the complexities of ancient vitreous material technology. As one example, the effect of varying the percentage of oxygen on the color of the finished product can be studied and then related to the colors of ancient artifacts. It is very important that such investigations spring from a close consideration of the ancient materials in their proper archaeological contexts.

Excavation of sites where ancient vitreous materials were made into artifacts can potentially provide valuable evidence for raw materials, furnaces, kilns, crucibles, and fuel used, in addition to the vitreous products and by-products themselves. Such a study would normally be carried out for an entire site or region, and the organization of the vitreous material industry should be linked to other high-temperature activities for which different pyrotechnological expertise and equipment (e.g., fuels, furnace or kiln design, and the use of ceramic materials) might have been shared or influenced vitreous material technology.

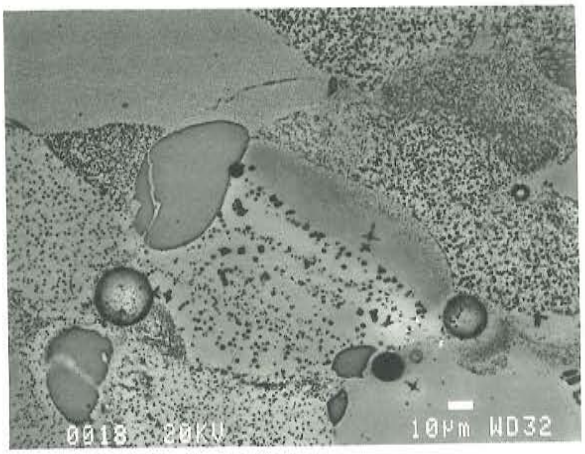

Fig. 18. Backscattered electron micrograph of fluorite crystals, seen as black particles 1–5 µ in size, in a 16th-century A.D. Chinese opaque turquoise cloisonné enamel. Discrete clusters of different-size fluorite crystals indicate that the enamel was fused within the cloisson in situ.

SCIENTIFIC ANALYSIS

A wide range of modern physicochemical techniques have been used to study vitreous materials.[161] Even though earlier investigations provided evidence for meaningful chemical compositional groups,[162] the techniques used up to about 1970 tended to be slow and time-consuming. Consequently, a data base for ancient vitreous material compositions only slowly developed. Recently, faster and more automated techniques of data collection and analysis have enabled ancient vitreous materials to be characterized more exactly over broader geographical areas and longer time spans. In some cases, the provenience of an artifact can be assigned only on the basis of its chemical composition.

The available scientific techniques provide a range of information about vitreous materials. Scanning electron microscopy (SEM) is particularly useful for photographing and identifying opacifying crystals and frits as small as 1 µ in size in glasses and glazes (fig. 18). The chemical compositions of vitreous materials can be determined using X-ray fluorescence analysis (XRF), electron-probe microanalysis (EPMA), and proton-induced X-ray emission spectrometry (PIXE). These surface techniques are minimally destructive or nondestructive. If surface layers have been weathered, however, they must be removed by

[161] J. Henderson, "The Scientific Analysis of Ancient Glass and Its Archaeological Interpretation," in J. Henderson ed., *Scientific Analysis in Archaeology and Its Interpretation* (Oxford University Committee for Archaeology Monograph 19, UCLA Institute of Archaeology, Archaeological Research Tools 5, Oxford 1989) 30–62.

[162] E.V. Sayre and R.W. Smith, "Compositional Categories of Ancient Glass," *Science* 133 (1961) 1824–26.

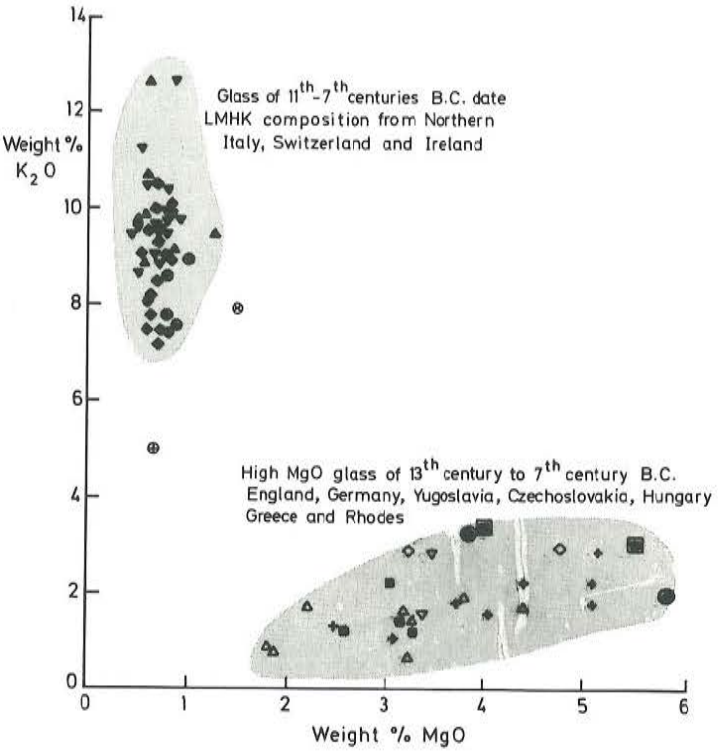

Fig. 19. Bivariate plot of magnesia (MgO) versus potassium oxide (K_2O) by weight percentage for 14th–7th century B.C. European glasses. Near Eastern and Egyptian glasses of the same time span group together with the high magnesia, low potassium examples.

polishing before analysis. An additional advantage of these techniques is that one can see what is being analyzed and thereby avoid impurities and structural irregularities. Neutron activation analysis (NAA) has the drawback that a ca. 200 mg sample must be pulverized; silica, the predominant constituent of vitreous materials, is also not measured, although the concentrations of other important trace and minor elements can be precisely determined. Mass spectrometry, another destructive technique requiring very small samples, is particularly useful in sourcing any lead that is present.[163] It is often advisable to use more than one technique, since each relies on different physical and chemical principles that result in different sensitivities.

Behind equipment paraphernalia and complexity, however, the most important consideration in any study of ancient vitreous materials is research design. To structure a clear and concise set of archaeological and technological problems to be investigated is essential. To do science for science's sake, though important, may not always contribute to the archaeological interpretation in a meaningful way. Fully integrating archaeological and scientific aspects is essential for resolving specific technological and cultural issues, as the following case study demonstrates.

A CASE STUDY: BRONZE AGE GLASS IN EUROPE

Much ancient glassmaking before the first millennium A.D. was dominated by soda-lime-silica technology. One interesting exception, however, occurred at the turn of the millennium (ca. 1100–1000 B.C., as dated by dendrochronology), when an entirely new vitreous technology emerged in parts of Europe. The industry is characterized by an innovative use of raw materials. Relatively high potassium oxide levels of up to 13% by weight are the earliest recorded instances of such glass; in soda-lime glass, potassium oxide is typically ca. 0.5% or 2–3% depending upon the soda source. The new glass is also characterized by low calcium oxide and magnesia levels.[164] High

[163] R.H. Brill, L. Barnes, and B. Adams, "Lead Isotopes in Some Ancient Egyptian Objects," in A. Bishay ed., *Recent Advances in Science and Technology of Materials* 3 (London 1974) 9–27.

[164] J. Henderson, "Glass Production and Bronze Age Europe," *Antiquity* 62 (1988) 435–51; and Henderson, "Electron Probe Microanalysis of Mixed-Alkali Glasses," *Archaeometry* 30 (1988) 77–91.

silica levels are caused by crystals dispersed through the glass, which reflect a relatively high proportion of light and make the glass appear "brilliant." The low magnesia and high potassium oxide levels of the glass have led to it being labeled LMHK. The earliest glasses of this type are concentrated in northern Italy (at the entrepôt of Fratessina at the head of the Adriatic) and Switzerland (at a Bronze Age site on Lake Neuchâtel). This European glass is very different from the ancient soda-lime glass of the Near East and Egypt (fig. 19) and of later periods (from the Hellenistic period to early medieval times) in Europe. Since it appears at about the same time that civilization and trade in the Near East and Egypt break down, possibly this glass helped to fill an economic vacuum. Even the LMHK Late Bronze Age glass found in eighth–seventh century B.C. Ireland (e.g., at Rathgall, Lough Gur, and Freestone Hill) can now be seen to be connected, however indirectly, to developments in northern Italy. By chemically analyzing well-provenienced and well-dated glass examples, it has thus been possible to shed light on economic, technological, and cultural developments in European prehistory.

Toward the end of the first millennium A.D. in Europe, a similar shift from soda-lime glass to the high potassium "forest" glass of the high medieval period occurred.[165] The technological change appears to have been relatively fast, and was due to economic and/or political disruptions in alkali (soda) supply, which forced glassmakers to use plant ashes that have a higher potassium oxide content. The enormous demand for stained glass windows in churches, which now had to be made from the "forest" glass, must have caused major dislocations in the organization of the industry. Scientific analyses of medieval "Limoges" enamels, a related vitreous technology of the period, show that while this industry shared in the use of high potassium glass, it also used glasses derived from probable recycled Roman tesserae and/or possibly early Islamic glass.

CONCLUSIONS

The study of ancient vitreous materials already ranges over a large area of time and space—from fourth-millennium B.C. Egyptian faience to the earliest glass of the third–second millennium B.C. Near East to European glazes and enamels of later periods. Outside of the Near East and Europe, the prehistoric high alumina soda-lime glasses of India and the high barium oxide glasses of Han China are evidence for silicate innovation.[166]

Analytical techniques promise both to broaden and deepen our understanding of vitreous technologies and their roles in societies. PIXE and inductively coupled plasma emission spectrometry (ICPS) enable chemical compositions to be measured at trace levels, providing very specific provenience data. Transmission electron microscopy (TEM) enables minute inclusions, down to a thousandth of a millimeter, to be photographed and analyzed.

In general, a sufficient number of closely datable artifacts is of overriding significance in the study of ancient vitreous materials. Analytical equipment can provide high-quality data, but the interpretation of the results is, in the end, strongly dependent on research design and whether or not the archaeological materials form coherent archaeological groupings.

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Xeroradiographic Imaging

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Xeroradiography is a radiographic imaging technique similar to photocopying techniques pioneered by the Xerox Corporation. The image is produced by placing the object of interest on a charged selenium plate and irradiating it with a standard X-ray source. Differences in charge density produce an image that is then rapidly transferred onto a 24.5 × 34.5 cm paper in a special copy machine. There is no film to develop. Typical exposures are lower in energy and exposure time than film radiography, and

[165] M. Dekowna, *Szklo W Europie wczesnosredniowiecznej* (Warsaw 1980); J. Henderson and I. Holand, "The Glass from Borg, an Early Medieval Chieftain's Farm in Northern Norway," *Medieval Archaeology* 36 (1992) 29–58.

[166] See esp. J. Bhardwaj ed., *The Archaeometry of Indian Glass* (New Delhi 1990); and R.H. Brill and J.H. Martin eds., *Scientific Research in Early Chinese Glass* (Corning, N.Y. 1991).

the results are available within 3–5 minutes of beginning the imaging process.[167]

As many studies have demonstrated, the images are easy to "read" and understand because edges, joints, or pores are enhanced with a halo effect.[168] The researcher evaluating xeroradiographic images, however, should understand the constraints of the technique. For example, the print is a mirror image of the object, unless reversed for publication purposes. The images also superimpose edge-enhanced surface detail onto the internal structure, and the side nearest the charged selenium plate is imaged in more detail than the side away from the plate. This effect can be significant if the artifact is very thick or is a hollow vessel.

The mechanism of achieving contrast is different from that of film radiography where the image is proportional to incident X-ray intensity on the film.[169] In electrostatic imaging, such as xeroradiography, charges accumulate at boundaries and around small details, and, much like a capacitor, a sufficiently large electric field will discharge across an edge. Any residual charge imbalance can discharge again and again, thereby producing an edge-enhancement. Because differing charge buildups and discharges occur, areas of varying density on a xeroradiograph cannot be compared quantitatively. The technique has a wide dynamic range in which many objects of diverse materials can be imaged in a single exposure; although densities are less well distinguished than with film radiography, discontinuities are enhanced. The wide range of densities that can be imaged and seen in a xeroradiograph are often obscured in a black-and-white print.

A positive xeroradiographic image will usually display the porosity and details of manufacture, while a negative image shows better the inclusions or higher-density features of an object.[170] One of the limitations of xeroradiography, however, is a 20-μ spatial resolution, which is coarser than the 3-μ resolution of current X-ray film.

EXAMINATION OF A GAZELLE RHYTON

A ceramic rhyton of a gazelle head in the Arthur M. Sackler Gallery of the Smithsonian Institution (fig. 20) provides an example of the technological information that can be obtained by xeroradiography.[171] Although a gift to the Smithsonian and unprovenienced, the vessel is possibly from Iran, and is dated by thermoluminescence to the first century B.C.–first century A.D.

The rhyton was clearly made in several pieces that had been joined together. Visual examination also suggested that the beaker portion of the vessel was either wheel-thrown or hand-built with strips or coils, whereas the rhyton head was hand-modeled. Very fine circumferential ridges, about 0.3–2.0 mm apart, can be seen on the interior using an intense penlight at a glancing or low angle to the surface, and indicate the smoothing of the surface.[172] In addition, circumferential grooves, about 3–4 cm apart, can be felt on the interior. Since these grooves are horizontal and do not spiral to the rim as is observed on wheel-thrown vessels, they are most likely to have been produced by hand-building. Because of weathering and pitting, no additional information could be ascertained from the exterior surface.

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[167] We thank Jane Norman and Thomas Chase of the Freer Gallery of Art and Arthur M. Sackler Gallery, and the staff of the Department of Radiography of the Alexandria (VA) Hospital, for their assistance in the xeroradiography of the gazelle rhyton discussed below. D. Stoneham of the Research Laboratory for Archaeology and the History of Art (University of Oxford) provided the thermoluminescent dating of the rhyton. A. Gunther, M. Goodway, and R. Henrickson offered useful comments on an earlier draft of this manuscript.

For discussion of the technique, see T.L. Thourson, "Xeroradiography," *Journal of the Society of Photo and Optical Instrumentation and Engineering* 56 (1975) 225–35.

[168] A.P. Middleton, J. Lang, and R. Davis, "The Application of Xeroradiography to the Study of Museum Objects," *Journal of Photographic Science* 40 (1992) 34–41; W.D. Glanzman and S.J. Fleming, "Xeroradiography: A Key to the Nature of Technological Change in Ancient Ceramic Production," *Nuclear Instruments and Methods in Physics Research* A242 (1986) 588–95; S. Heinemann, "Xeroradiography: A New Archaeological Tool," *AmerAnt* 41 (1975) 106–11.

[169] J.N. Wolfe, "Xeroradiography: Image Content and Comparison with Film Roentgenograms," *American Journal of Roentgenology* 17 (1973) 690–95.

[170] P.B. Vandiver, W.A. Ellingson, T.K. Robinson, J.L. Lobick, and F.H. Sequin, "New Applications of X-Radiographic Imaging Technologies for Archaeological Ceramics," *Archeomaterials* 5 (1991) 185–207.

[171] The rhyton, inv. no. S1987.31, has been published in *Asian Art in the Arthur M. Sackler Gallery: The Inaugural Gift* (Washington, D.C. 1987) 24 no. 16, and 43; T.S. Kawami, *Ancient Iranian Ceramics from the Arthur M. Sackler Collections* (Washington, D.C. 1992) 222 no. 141; and A. Gunter, "The Art of Eating and Drinking in Ancient Iran," *Asian Art* 1:2 (1988) 39.

[172] P.B. Vandiver, "Sequential Slab Construction: A Conservative Southwest Asiatic Ceramic Tradition, ca. 7000–3000 B.C.," *Paléorient* 13 (1987) 9–35; R.C. Henrickson, "Wheelmade or Wheel-Finished? Interpretation of 'Wheelmarks' on Pottery," in P.B. Vandiver, J. Druzik, and G.S. Wheeler eds., *Materials Issues in Art and Archaeology* 2 (Pittsburgh 1991) 523–41.

Fig. 20. Ceramic gazelle rhyton, possibly from Iran, ca. first century B.C.–first century A.D. (Arthur J. Sackler Gallery, Smithsonian Institution S1987.31). Made of a soft (Mohs 2.5), tan clay body, the vessel balances on its handle, and has a spout hole below the mouth.

The xeroradiographs (fig. 21a–b) confirm that the beaker portion of the rhyton was hand-built with strips or coils. The process of throwing results in the alignment of air pockets in the clay body at an angle of about 30–45° from the throwing grooves and ridges.[173] In contrast, coiling techniques produce a horizontal alignment of porosity, as is observed in figure 21a. It should be noted that, if the vessel wall were shaped after coiling, porosity alignment might also be angled off from the horizontal.

The uneven wall thickness of the carefully sculpted head supports the hypothesis of hand-modeling as its method of manufacture. Rounded fingertip-sized impressions, but no indentations made by pointed or blunt tools, are seen on the head's interior. Because some of the exterior features are undercut, the head could not have been made in a single, open-face mold. The lack of joints indicates that the head was made from a single piece of clay.

Even though molding and throwing would have been more efficient, the care and excellence in craftsmanship of the gazelle rhyton, in particular the quality of its sculpting using the labor-intensive methods of hand-building and modeling, suggest that this was a luxury item that would not have been produced in large numbers. The method is unlike that used for other Greek zoomorphic rhyta in which the head section is molded and the beaker is thrown. Microscopic examination of the Greek rhyton collection at the Ashmolean Museum shows clear marks where the two molded halves of the heads were joined together, and spiral throwing-ridges and occasional diagonal stretch marks in upper sections of the beaker portions of the vessels.

It is also surprising that the firing temperature of the gazelle rhyton was so low that the body is quite porous and permeable to liquids. Cracks that appeared during forming and drying are present at the top of the handle, the beaker joint of the extra reinforcement clay strip extending from the throat to the base of the beaker (fig. 21a), and below the handle in the wall of the beaker. Four grooves had been created with a rounded tool below and parallel to the handle after the clay body was stiff and somewhat dry. Three of these grooves deformed the clay body sufficiently to have produced cracks in the grooves from which any liquid contents might have escaped.

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[173] P.B. Vandiver, "The Implications of Variation in Ceramic Technology," *Archeomaterials* 2 (1988) 139–74.

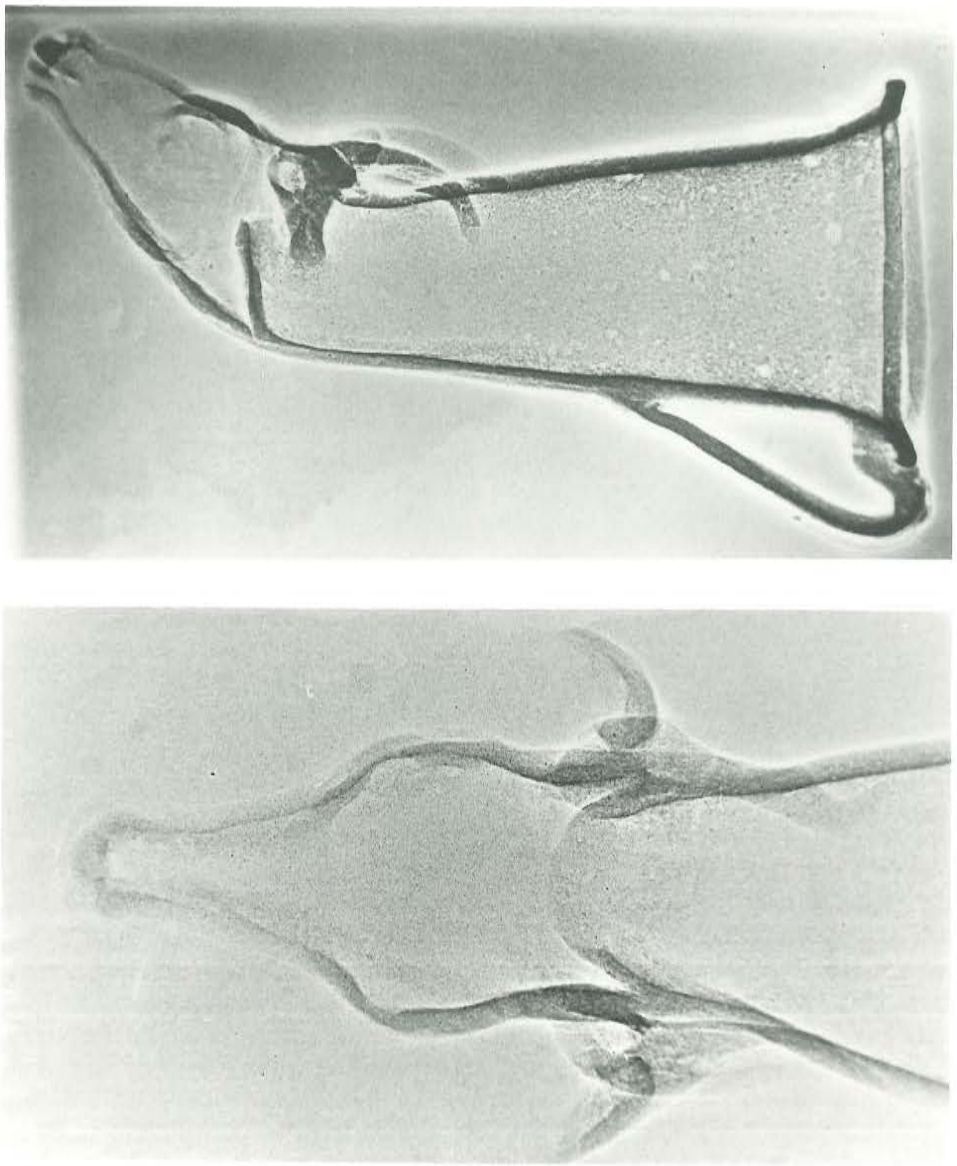

Fig. 21. a) Xeroradiograph of the left side of the gazelle rhyton (fig. 20), showing the spout hole beneath the mouth, a second hole through the mouth that was later covered over with clay, the uneven wall thickness of the carefully hand-modeled head, the extra clay strip added between the throat of the head and the base of the beaker, and the passage between the beaker and the head. The attached beaker is uniformly shaped, with an attached strip of clay for the handle. b) Xeroradiograph of the top of the rhyton, showing the attachment of the head to the beaker, and the partial rounding of the beaker base where a passage opens between the latter and the head.

Does the gazelle rhyton represent an ancient example in which technical understanding did not match the artisan's expressive sculptural capabilities? Examination using xeroradiography combined with other analytical techniques not only has allowed identification of the methods and sequence of manufacture, but also has led to further questions about the intended function and quality of craftsmanship employed in the vessel.

The xeroradiographic analysis of the gazelle rhyton illustrates the effectiveness of this nondestructive technique in discovering ancient manufacturing methods. The technique can also be applied to many other materials—textiles, paper, wood, metals, corrosion products, etc.—and types of artifacts.

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The Provenience Analysis of Amber

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Amber (figs. 22–23) is the name originally attached to a fossil tree resin that occurs naturally over a large part of northern Europe. It is thought to have originated in a forested area of southern Scandinavia, but only secondary, tertiary, and higher-order deposits are known, and among these, the Jutland peninsula and the shores of the eastern Baltic Sea are by far the richest. But due to later geological events—the formation of the Tethys Sea, the Ice Ages, and the river systems that were formed when the glaciers melted—it was carried west to the coast of England, south to parts of the Netherlands, the North German plain, and southeast throughout all of Poland and well into European Russia. Because of the wide distribution of amber in archaeological contexts throughout the Old World, attempts to determine its provenience go back over more than a century.

In the early 19th century, the somewhat misleadingly named "Baltic amber" was held to be the only source of amber artifacts, and when these were found in excavations outside the natural range of distribution, they were *ipso facto* assumed to be imports from the north. In the course of the 19th century, mineralogists discovered, described, and named as many as 100 fossil resins occurring throughout Europe as well as other continents. In 1872, the Italian mineralogist Capellini first suggested that some of these non-Baltic deposits, including those he himself had found near Bologna, might well have served as raw material for amber artifacts in prehistoric times, and that a Baltic origin should no longer be assumed.[174] The suggestion was not well received by most archaeologists and led to a quite heated discussion during the International Congress of Prehistoric Anthropology and Archaeology in Stockholm in 1874.[175]

But the question had been raised, and the attempt to answer it by scientific means constitutes an important and instructive chapter in the early history of archaeometry. The German apothecary Otto Helm set out to identify Baltic amber by chemical analysis. The method he used was the quantitative determination of a characteristic component of Baltic amber, succinic acid, which can be liberated from the resin

Fig. 22. Piece of worked amber from Palaeolithic deposit in Gough's cave, Cheddar, Somerset county, southwest England. (E.K. Tratman, *Proceedings, University of Bristol Spelaeological Society* 6 [1953] pl. 26)

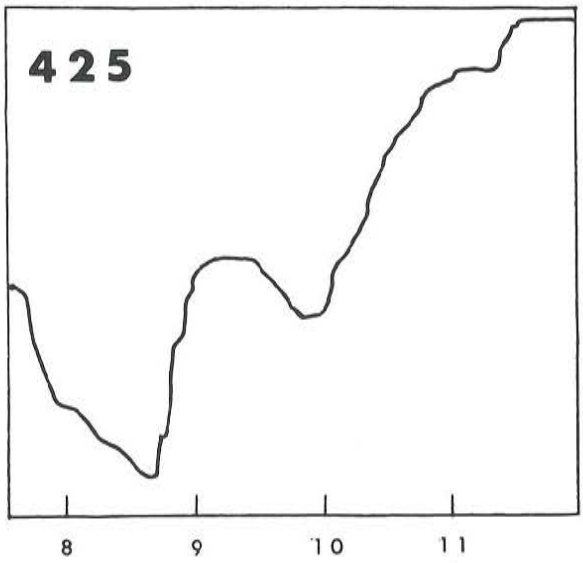

Fig. 23. Infrared spectrum (no. 425), over the diagnostically significant region from 7.5 to 12.0 μ (833–1333 cm^{-1}), of amber piece from Gough's cave (fig. 22), showing that it is of Baltic origin and must have been brought to southwest England by human activity. (C.W. Beck, *Proceedings, University of Bristol Spelaeological Society* 10 [1965] fig. 64)

[174] G. Capellini, "Über das Vorkommen von Bernstein im bolognesischen und anderen Punkten Italiens," *ZfE, Verhandlungen* 1872, 198.

[175] H. Stolpe, "Sur l'origine et le commerce de l'ambre dans l'antiquité," and ensuing discussion, *Congrés international d'anthropologie et archéologie préhistoriques* (Stockholm 1874) 777–817.

by hydrolysis or pyrolysis in amounts ranging from 3 to 8%. Over a period of 25 years, Helm sought to show that Baltic amber was the only source of archaeological amber artifacts found in the Old World, including most famously the amber beads Schliemann had found in Grave Circle A at Mycenae.[176] Helm was not quite the detached, objective scientist: his explicit goal was to prove Capellini wrong. When it became evident that amber-like fossil resins native to Italy, Romania, France, and Portugal contained as much or more succinic acid as Baltic amber,[177] he high-handedly dismissed that evidence and claimed that he could recognize these resins as non-Baltic by sight. Apart from its central methodological flaw, this early provenience analysis of amber had other disadvantages. As much as a gram of an archaeological amber find had to be destroyed for a single analysis, and the natural reluctance of archaeologists to sacrifice what would often be an entire singular find limited the application of the succinic acid method to a few dozen cases. Lastly, the question of provenience was often cast too narrowly: finds from an excavation were compared to Baltic amber, on the one hand, and to a single variety of non-Baltic amber, such as Sicilian amber, on the other. If the finds were "more like" one than the other reference source, they were assigned to it in blatant violation of the fallacy of the excluded middle.

The failure of this early instance of provenience analysis by physicochemical means had two predictable results: it lowered the confidence of archaeologists in the usefulness of the natural sciences in the service of archaeology, and it discouraged further work toward solving the amber problem. No attempts to determine the provenience of amber were made for more than half a century after Helm's death. When the search for a reliable method was resumed, the arsenal of analytical chemistry had been enlarged by a range of powerful instrumental methods. One of these, infrared spectroscopy, has provided the solution to a very old question. When infrared light passes through a material, those wavelengths are absorbed that correspond to the amount of energy required to support the vibrations of atoms within molecules. The emerging infrared light lacks those wavelengths and thus furnishes a pattern in which they are diminished or missing. The resulting spectrum gives information about the chemical structure of the material, but it can also be used, purely empirically, as a "fingerprint" characteristic of this, and only this, material.

In 1964, we could show that Baltic amber had a unique infrared absorption spectrum.[178] That spectrum, incidentally, proved that the age-old notion that Baltic amber derives from pine trees, as claimed by Pliny the Elder, is wrong. The spectra clearly place the botanical origin not in the genus *Pinus* but in the closely related genus *Araucaria*.[179] For the purposes of archaeological provenience analysis, however, the uniqueness of the "fingerprint" is enough.

Learning from the shortcomings of Helm's work, we proceeded with methodological rigor. The infrared spectra of more than 2,000 samples of fossil resins, collected from the mineralogical collections of natural history museums in Europe and the United States, were determined. No European fossil resin matched the infrared spectrum of Baltic amber, which is characterized by a single absorption in the wave number range between 1100 and 1300 cm^{-1} that is preceded by a broad shoulder (fig. 23). Infrared spectroscopy thus offers a reliable way of identifying Baltic amber with absolute certainty. Like other instrumental methods, the infrared test requires only a very small sample, typically between 1 and 2 mg, and can be performed in about 20 minutes. That has made it possible, over the course of the last 30 years, to analyze more than 5,000 archaeological amber finds from excavations throughout the Old World, with the support of many private and public foundations who have made the project possible, most notably the Division of Anthropology of the National Science Foundation. The program has been conducted under the aegis of the Union internationale des sciences préhistoriques et protohistoriques since 1978, when the U.I.S.P.P. established a "Committee on the Study of Amber" in recognition of the potential of these analyses to elucidate the amber trade and the amber routes in prehistoric Europe.

Because of space limitations, a detailed account of our results cannot be provided here; a summary

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[176] O. Helm, "Über die Herkunft des in den alten Königsgräbern von Mykenae gefundenen Bernsteins und über den Bernsteinsäuregehalt verschiedener fossiler Harze," *Schriften der naturforschenden Gesellschaft in Danzig*, N.F. 6:2 (1885) 234–39.

[177] C.W. Beck, "Amber in Archaeology," *Archaeology* 23 (1970) 7–11.

[178] C.W. Beck, E. Wilbur, and S. Meret, "Infrared Spectroscopy and the Origin of Amber," *Nature* 201 (1964) 256–57.

[179] C.W. Beck, E. Wilbur, S. Meret, D. Kossove, and K. Kermani, "The Infrared Spectra of Amber and the Identification of Baltic Amber," *Archaeometry* 8 (1965) 96–109.

up to 1986 of more than 100 publications is available.[180] It should be noted, however, that the overwhelming majority of the archaeological amber finds of south-central and southern Europe are indeed exports of Baltic amber from the north, including all of Schliemann's finds from Bronze Age Greece. The few exceptions are instructive: a find of amber in the Vayenas tholos at Pylos, for example, is of Sicilian, not of Baltic, amber, as is a find from the Aeneolithic necropolis of Laterza in southern Italy.[181] A presumed find of amber from Tell Asmar (ancient Eshnunna), dated to 2500–2400 B.C., has been shown to be not amber, but East African copal.[182] Continued research on amber promises to shed additional light on its cultural and economic importance in antiquity.

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Skeletal Remains

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The study of human remains from archaeological contexts is one of the many research areas comprising physical anthropology. In contrast to archaeological research that deals with the material culture resulting from human activities, skeletal analyses focus directly on the people responsible for such activities. The methods used in skeletal analyses are based on those employed for diagnostic purposes in forensic anthropology, medicine, epidemiology, and anthropological studies of living populations. They are directed toward determining population origins and kinship, nutrition, disease status, and longevity of past populations. From a broader perspective, they provide the basic data for studying the nature and rate of human evolution.

A skeletal investigation begins by determining the manner in which the individual(s) was interred, as evidenced by the position of the bones (whether an intact or disturbed burial). This is followed by the determination of age and gender, which are used to estimate life expectancy for the population studied (palaeodemography). Physical characteristics of individuals are usually defined by measurement of the size and shape of the skull and long bones (morphometry), as well as the presence of discrete traits. Resemblances between individuals and populations are then used to evaluate kinship and population affinities. More sophisticated methods now coming into use include analysis of mitochondrial and nuclear DNA extracted directly from the skeletal remains, which provide direct information on the genome and pathogens present. Evaluation of nutrition and disease status, as well as evidence of trauma (palaeopathology), provides additional information on the life history of individuals and an estimate of the quality of life for the population under study. Marked differences in incidence of disease between subgroups may result from differences in occupation and/or access to available resources. This comprises an important element of mortuary studies that investigate the correlation of social status to burial type.

The techniques used in the above analyses range from the simple to the sophisticated. Age, gender, gross pathology, and phenotype can be determined from visual assessment, supplemented by measurements made with calipers and tapes.[183] More sophisticated studies using radiographs, computerized tomography (c–t) scans, and optical and scanning electron microscopy improve the degree of accuracy achieved, especially for determination of age and pathology, while biochemical analyses of trace elements and isotopes can provide additional information on diet.[184]

As in all archaeological studies, many factors affect the reliability of the available samples, including excavation priorities or constraints, burial practices of the population under study, and soil conditions causing poor preservation (especially of fragile in-

[180] C.W. Beck, "Spectroscopic Investigations of Amber," *Applied Spectroscopy Reviews* 22 (1986) 57–110.

[181] C.W. Beck and H. Hartnett, "Sicilian Amber," in J. Bouzek and C.W. Beck eds., *Amber in Archaeology* (Prague, forthcoming).

[182] C. Meyer, J.M. Todd, and C.W. Beck, "From Zanzibar to Zagros: A Copal Pendant from Eshnunna," *JNES* 50 (1991) 289–98.

[183] W.M. Bass, *Human Osteology*[3] (Columbia 1987) is a standard manual for bone identification and measurement.

[184] For methods used in skeletal analyses and life history reconstruction, see Y.M. Iscan and K.A.R. Kennedy, *Reconstruction of Life from the Skeleton* (New York 1989); and S.R. Saunders and M.A. Katzenberg, *The Skeletal Biology of Past Peoples: Research Methods* (New York 1992).

fant bones). To these must be added the "blurring" factor that is due to the fact that skeletal assemblages do not usually represent one point in time, but rather the accumulated deaths of several generations. Migration, immigration, and/or differences in fecundity over time may thus contribute to fluctuations in the age/sex profiles represented.[185]

THE NATUFIANS: A CASE STUDY FROM THE NEAR EAST

Skeletal remains from the Epipalaeolithic or Natufian period illustrate the potential and limitations of skeletal analyses in resolving specific issues, especially when dealing with small, biased samples. Dated between ca. 12,500 and 10,500 B.P., Natufian sites show a marked increase in settlement size, permanent habitation, and architecture as compared with the preceding Kebaran period. These developments are coupled with an increase in artifacts and features that are generally attributed to cereal collection and utilization, such as pestles, querns, sickle blades, and storage pits. In the succeeding Neolithic period, similar tools and facilities are definitely being used to process and store plant domesticates.

The Natufian period has been subdivided into three phases on the basis of tool types, and most research on this culture has been directed toward understanding the "triggers" that were responsible for the transition from hunting and gathering to plant and animal domestication and the establishment of permanent settlements throughout the Near East.[186] Skeletal remains have been found at most Natufian sites, and research has focused on population affinities, disease, and diet.[187]

SAMPLE SIZE AND REPRESENTATIVENESS

Natufian skeletal remains, which have been recovered from the sites of Shukbah, Kebara, El Wad, Eynan, Nahal Oren, Erq el Ahmar, and Hayonim in Israel and the West Bank, are the primary focus here. Numerous sites in Jordan (e.g., Beidha) and in Syria (e.g., Abu Hureyra on the Euphrates), however, have also yielded Natufian material.

Sample sizes for Natufian sites in Israel and the West Bank range from seven individuals at Erq el Ahmar to more than 100 at Eynan. At most sites, both primary (intact) and secondarily disturbed burials were found. Preservation of bones ranged from moderate to poor, and the frequency of infants varied from site to site. Because of poor preservation, age or gender could not be reliably defined for more than half the adults excavated, while detailed morphometric analyses could be carried out on even fewer specimens. The teeth and mandibles were best preserved.

The extent to which the Natufian age distribution is biased by differential burial practices can be roughly estimated by comparing life-tables calculated for living populations with those for Natufians. As might be expected, infant deaths in a modern society are inversely related to affluence, being most frequent in the first months of life and declining later in childhood. None of the Natufian assemblages so far studied, however, fits this model. Diagenesis (differential preservation) cannot account for this discrepancy, since the relative number of infant remains recovered from sites with good bone preservation is not any greater than that for sites with poor preservation. The most economical explanation, which has also been established for other periods, would appear to be that most Natufian infants were not buried in the same location as older children and adults. The age distribution is then obviously skewed, limiting the validity of palaeodemographic analyses. A further confounding factor is the small sample size. The discovery of only several hundred individuals for a ca. 2,000-year time span implies that there are many gaps in the skeletal record, which is in accordance with the archaeological finding of periodic abandonment of sites.

While detailed palaeodemographic analyses of Natufian populations are clearly inappropriate, an alternative approach that provides some information on longevity has been to assess the ratio of younger to older adults. In the Natufian period, as in most hunter-gatherer groups studied, very few adults sur-

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[185] J.W. Wood et al., "The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples," *CurrAnthr* 34 (1992) 343–70.

[186] For recent overviews of the Natufian period, see A. Belfer-Cohen, "The Natufian in the Levant," *Annual Review of Anthropology* 20 (1991) 167–86; M.N. Cohen, *The Food Crisis in Prehistory* (New Haven 1977); and Bar-Yosef and Valla (supra n. 66).

[187] Recent summaries and comprehensive bibliographies of skeletal analyses appear in Bar-Yosef and Valla (supra n. 66) by A. Belfer-Cohen, L.A. Schepartz, and B. Arensburg ("New Biological Data for the Natufian Populations in Israel," pp. 411–24) and P. Smith ("The Dental Evidence for Nutritional Status in the Natufians," pp. 425–32). Also see O. Soliveres-Massei, *Les hommes de Mallaha (Eynan) Israel*, Pt. 2: *Étude anthropologique* (Mémoires et travaux du Centre de recherches préhistoriques français de Jerusalem 7, Paris 1988) 157–204; and P. Smith, O. Bar-Yosef, and A. Sillen, "Archaeological and Skeletal Evidence for Dietary Change during the Late Pleistocene/Early Holocene in the Levant," in M.N. Cohen and G.J. Armelagos eds., *Paleopathology at the Origins of Agriculture* (New York 1984) 101–36.

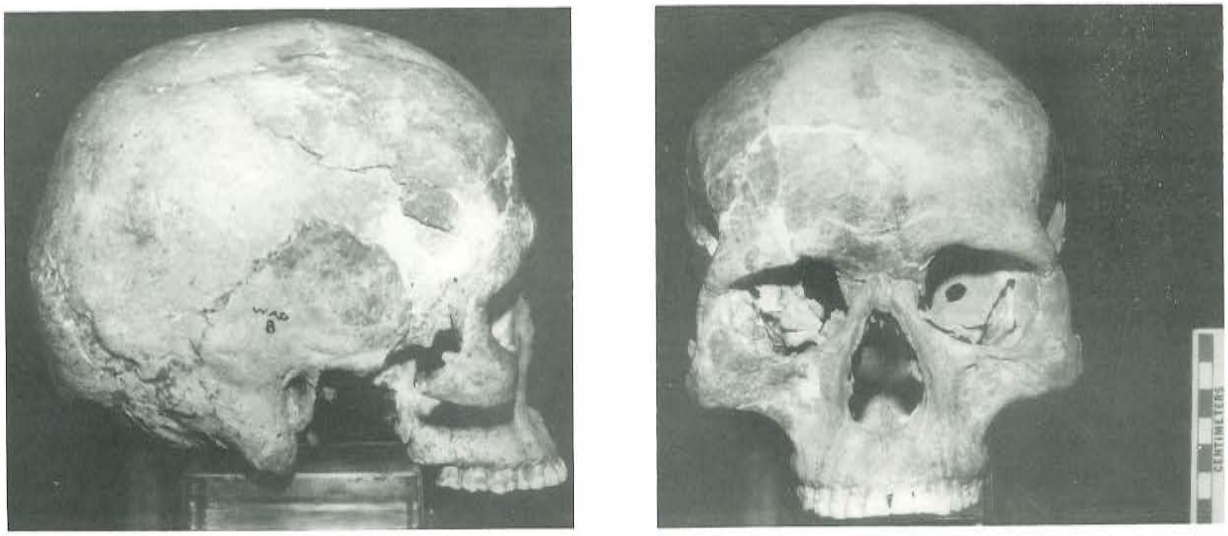

Fig. 24. Side and frontal views of a skull of a Natufian male from El Wad

vived beyond age 50. By contrast, ancient agricultural societies in Israel and the West Bank had between 10 and 20% survival rates to this age.[188]

MORPHOMETRY AND FUNCTIONAL ANATOMY

All who have studied the Natufians from these sites in Israel and the West Bank agree on the overall physical similarities of the populations. Individuals are characterized by short to medium stature, large, somewhat dolichocranic (long) skulls, and short, broad faces. The teeth show a high incidence of lingual tubercles on upper incisors and large Carabelli's cusps on upper first molars. The Natufians differ markedly from contemporary populations in North Africa and the Nile Valley, which are extremely robust, with very much larger skulls and teeth, and well adapted to hunting and eating large game (cf. figs. 24–25).[189]

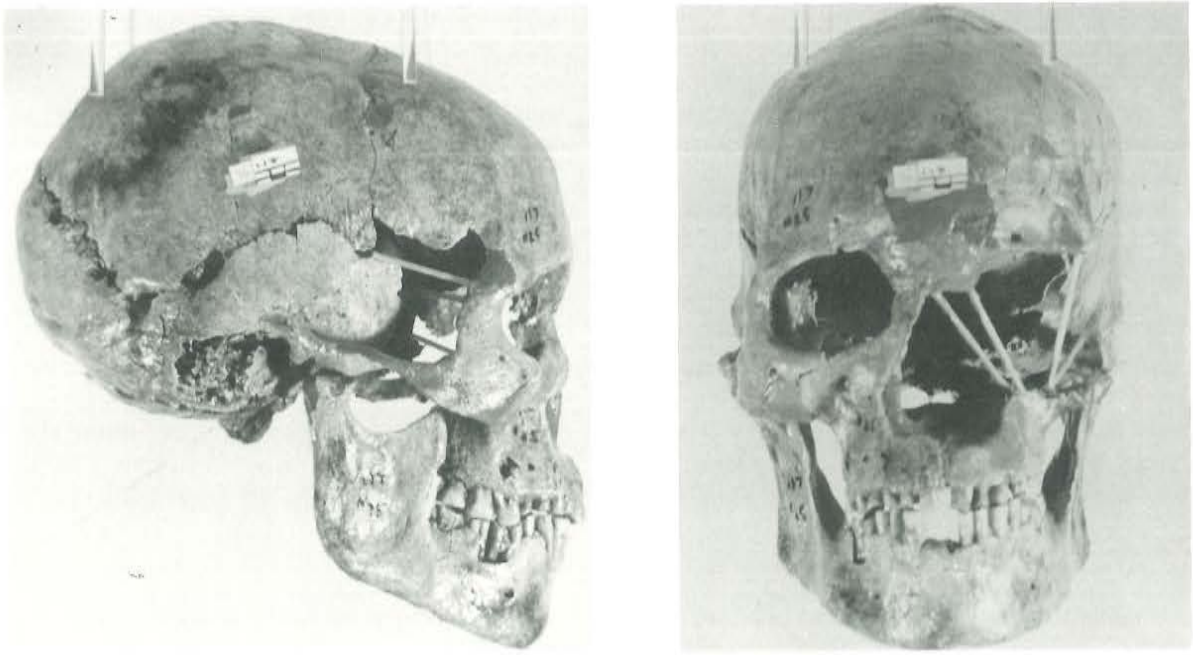

Fig. 25. Side and frontal views of a skull of a Nubian male from West Sahaba

[188] Smith et al. and Smith (supra n. 187).

[189] P. Smith, "Evolutionary Trends in Pre-Agricultural Communities," *Rivista di antropologia* (Rome), suppl. 61 (1988) 281–94.

At Hayonim, at least seven adults (29% of the sample population) have a congenital absence of a third molar, while its overall frequency in Natufians is of the order of 10%. This condition is inherited, so that the exceptionally high frequency at Hayonim indicates close kinship among at least some of those buried there. In a preliminary study, Ferembach reported that the Natufians from Eynan appeared to be taller and have larger heads than individuals from other sites, suggesting that these differences might be related to nutrition.[190] This hypothesis, however, has not been supported by the findings on the relative incidence of disease at Hayonim and elsewhere, nor is the number of intact specimens on which detailed morphometric studies have been carried out sufficient to determine intra- and intersite variation. Highlighting the limited sample sizes available for comparative studies is the fact that stature estimates for the Lower Natufian phase at Eynan were based on only one complete male femur and three incomplete femurs.[191]

Small sample sizes similarly limit intersite and interperiod analyses of cranio-facial parameters. Fortunately, mandibles are better preserved than other skeletal elements, and the number available for analysis is sufficient for basic statistical inferences. The data show that a significant reduction in mandibular robusticity occurred during the Natufian period, thus corroborating the evidence for changing diets and reduced selective pressures on jaws based on patterns of dental disease.[192]

In a recent article, Renfrew stated that skeletal analyses are of limited value for studying population origins, since skeletal parameters may be modified by environmental stress.[193] Certainly, environmental stress during childhood may depress growth, but other skeletal and dental parameters are less affected. Indeed, in the classical study by Boas, usually quoted in support of plasticity of cranial measurements, the differences found in head length between immigrants to the United States and their offspring were small.[194] Later studies have found that most parameters of the cranio-facial complex show a high degree of hereditability and so are reliable for studies of population distance.[195] At the same time, the possible influence of stressed conditions on growth

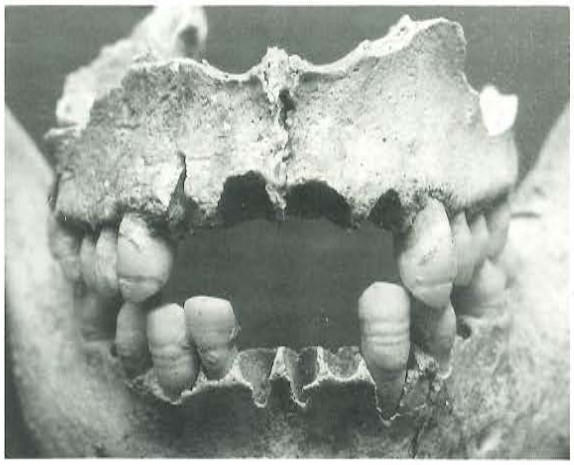

Fig. 26. Teeth with hypoplastic defects, present as parallel grooves and pits on the enamel surface, from Achziv, Israel, ninth century B.C.

can be gauged by reference to the presence of developmental defects such as dental hypoplasia and growth arrest lines.

A supplementary approach to population studies has been the use of dental traits, which have been found to be extremely reliable in studies of the population affinities of modern and ancient societies.[196] Renfrew's criticisms regarding the effect of environmental stress on skeletal morphometry can then be countered by careful evaluation of the severity of developmental defects in the samples compared, as well as by the use of parameters that show a high degree of heritability such as dental traits. For the Natufians, such studies have emphasized the similarities of Natufian populations from all sites and phases.

PALAEOPATHOLOGIES WITH CHANGING DIET

Environmental stress in the Natufians has been assessed in terms of developmental defects and other pathologies. Fortunately for the physical anthropologist, the timing and severity of events, which are sufficiently stressful to depress growth, result in permanent scars in the teeth and bones that can be readily identified in adults. The latter include hypoplastic defects of teeth (fig. 26) and hypercalcified growth arrest lines (Harris lines) in long bones. Simi-

[190] D. Ferembach, "Squelettes du Natoufien d'Israel: Étude anthropologique," *Anthropologie* 65 (1961) 46–66.

[191] Soliveres-Massei (supra n. 187).

[192] Smith et al. (supra n. 187).

[193] C. Renfrew, "Archaeology, Genetics and Linguistic Diversity," *Man* 27 (1992) 445–78.

[194] F. Boas, "Changes in the Body Form of Descendents of Immigrants," *American Anthropologist* 14 (1912) 530–63.

[195] S.O.Y. Keita, "An Analysis of Crania from Tell-Duweir Using Multiple Discriminant Functions," *American Journal of Physical Anthropology* 75 (1988) 375–90.

[196] The rationale and methods used in dental anthropology are reported in a series of classic articles in *Dental Anthropology*, edited by D.R. Brothwell (New York 1963). Note especially the article by the late A.A. Dahlberg, "Analysis of the American Indian Dentition," pp. 149–78.

Fig. 27. Radiograph of humeri, showing variation in cortical thickness of bones (most apparent on the second bone from the bottom, as the white bands along the length of the bone), Dor, Israel, 15th–18th century A.D.

larly, loss of cortical bone (periostitis), resulting from chronic malnutrition and/or disease in the weeks preceding death, can also be diagnosed from the bones (fig. 27). The frequency of hypoplastic defects in Natufian teeth is approximately 50%, compared with approximately 33% in Middle Palaeolithic *Homo sapiens* and 90% in later agricultural populations of Israel and the West Bank. The relative frequency of growth arrest lines in long bones shows a similar patterning that demonstrates the intermediate status of the Natufians. Other pathological signs, such as reduction in bone mass (osteopenia) and inflammatory or degenerative lesions of the bones, also occur in lower frequencies in the Natufians than in later agricultural populations.[197]

The results obtained from the study of pathologies and developmental defects thus concur in aligning the Natufians with hunter-gatherers, who show little pathology, rather than with agriculturalists. Some researchers, however, have argued that few signs of developmental lesions or other pathologies will be found if individuals succumb rapidly to disease rather than surviving long enough for the body to respond.[198] Thus, they hypothesize that a low frequency of growth insults may equally characterize populations with high or low stress levels. Certainly, a catastrophe or severe epidemic may cause sudden death of large numbers of the population over a short period of time. Unless the population is decimated, however, some equilibrium is eventually reached, and survival for even two or three days is sufficient for a visible response to infection or severe malnutrition to occur in the bones or developing teeth. For most Natufian sites, the samples extend over several generations, so that we are not dealing with a single episode. The frequency of developmental defects and other skeletal pathologies in samples from the different sites and periods is stable, indicating that the level of environmental stress affecting the bony tissues was fairly constant. In contrast, the severity of dental disease increased over time, pointing to a marked dietary change within the Natufian period.

Hunter-gatherers typically eat foods that require prolonged mastication and are largely self-cleansing. Teeth of early *Homo sapiens*, like those of contemporary hunters and gatherers, are characterized by little caries or periodontal disease, while attrition rates vary according to the abrasiveness of the diet. Most agriculturalists, on the other hand, eat softer foods, including large quantities of cooked carbohydrates that stick to the teeth. This predisposes agriculturalists to dental caries and periodontal disease, while attrition rates vary not only with the abrasiveness of the food but also with methods of food preparation. For example, flour ground using simple milling stones produces considerable grit that contributes to rapid tooth wear. For this reason, early agriculturalists show severe attrition, in addition to higher rates of caries and periodontal disease than hunters and gatherers.

Dental disease patterns in Natufian populations indicate increased consumption of cooked carbohydrates over time. The dental disease patterns of the Natufians more nearly resemble those of early agriculturalists than those of hunter-gatherers in rates of attrition, caries, and periodontal disease. Moreover, when specimens are separated out by phase, the severity of dental disease can be seen to increase over time, suggesting a gradual increase in

[197] Smith et al. (supra n. 187).

[198] Wood et al. (supra n. 185).

cereal consumption. Studies based on strontium/calcium (Sr/Ca) ratios of bones provide independent support for the hypothesis of increased cereal consumption in the Natufian period.[199] Recently, acorns have been proposed as the main source of the increased carbohydrate consumption in the Natufian period,[200] despite their absence from the plant remains. This hypothesis still remains to be tested by dental microwear analysis using scanning electron microscopy. Since acorn flour lacks the abrasive phytates present in the husks and stalks of cereals, it should result in a smoother, more polished surface of the abraded teeth than that produced by cereal consumption.

CONCLUSIONS

Research on the skeletal remains of the Natufians is ongoing. As this brief review has shown, skeletal analyses offer unique perspectives on past societies and individuals, and can provide specific answers to questions that cannot be addressed by other means. The latest innovation is nuclear and mitochondrial DNA analysis of ancient skeletal remains and mummified tissues, which promises to be a very powerful technique with wide application. While the cost of such analyses presently prohibits their use on a routine basis, they should enable the physical anthropologist to test hypotheses derived from morphometric and palaeopathologic analyses by relating a known pathology to a DNA mutation or to the presence of a specific pathogen as identified by its DNA. Many questions involving the origins, relationships, and descendants of prehistoric and historical populations, as well as their behavior and standard of living, should also eventually be answerable.

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Immunochemistry Applied to Archaeology

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THE IMMUNE RESPONSE

Immunology is the study of the reaction between the immune system of a living organism (the host animal) and a foreign substance (i.e., an infectious agent or substance that the organism does not recognize as "self"). Most living creatures possess an innate immune system, which does not require prior contact with a foreign substance (i.e., an infectious agent) in order to be effective. Acquired immunity—the ability to build up resistance to infection by an immune response—is a characteristic of vertebrates including humans.

The immune response includes a recognition system in which the host animal creates "designer molecules" called antibodies that are capable of recognizing and reacting with the invading substance (the antigen).[201] Immunochemistry is the application of this antibody-antigen reaction in contexts outside the host creature (referred to as *in vitro*), to detect and quantify specific compounds, such as the proteins in blood. Immunochemistry normally triumphs over conventional organic analysis because its detection limits are much lower.

The recognition process itself works on the basis of molecular geometry (in much the same way as the docking of a space shuttle!). The foreign substance (or antigen—the molecule that *gen*erates the *anti*body) enters the host via the bloodstream or by transport across a mucous membrane (e.g., the cells lining the lungs or gut). It then encounters particular cells called B-lymphocytes. Each B-lymphocyte is capable of producing only one type of antibody that will have a particularly shaped "docking mechanism." The antigen selects the most suitable B-lymphocyte cells, and triggers them not only to produce antibodies, but also to reproduce themselves, thus enabling the host to respond more quickly to

[199] M. Schoeninger, "The Agricultural 'Revolution': Its Effect on Human Diet in Prehistoric Iran and Israel," *Paléorient* 7 (1981) 73–92; A. Sillen and J.A. Lee-Thorp, "Dietary Change in the Late Natufian," in Bar-Yosef and Valla (supra n. 66) 399–410.

[200] D.L. Olszewski, "Subsistence Ecology in the Mediterranean Forest: Implications for the Origins of Cultivation in the Epipalaeolithic Southern Levant," *American Anthropologist* 95 (1993) 420–35.

[201] C.A. Janeway, "How the Immune System Recognizes Invaders," *Scientific American* 269:3 (1993) 61–67.

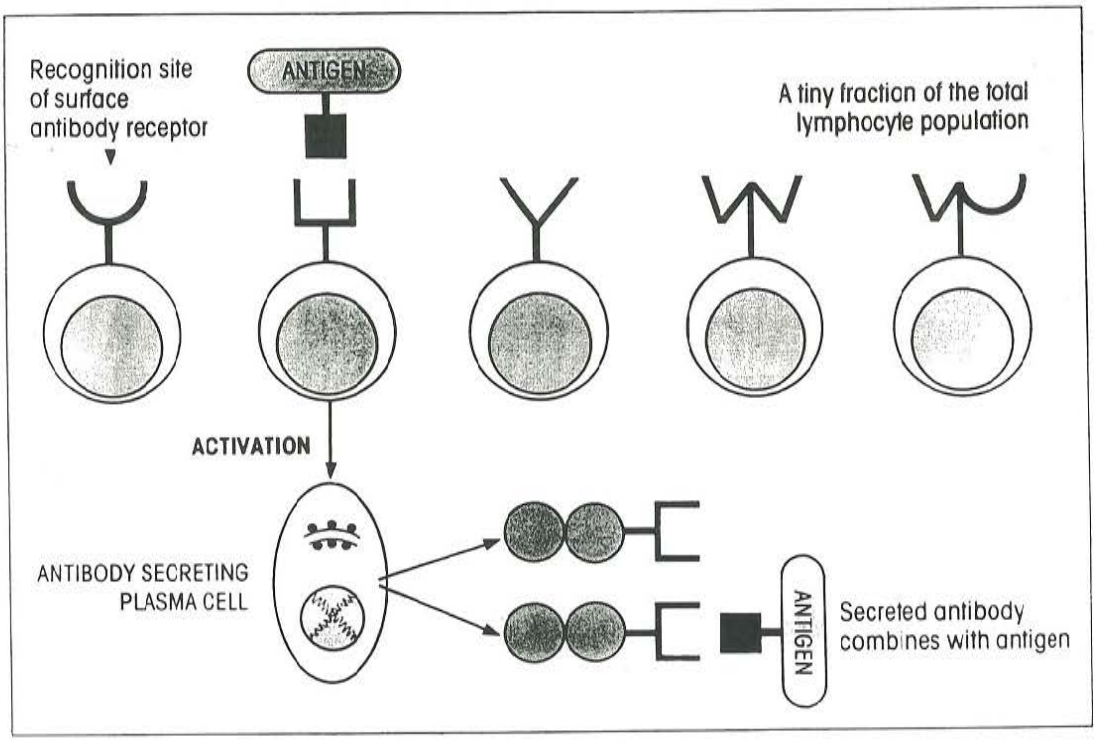

Fig. 28. Schematic diagram of antibody-antigen binding and activation. The invading antigen binds only to the antibody receptor to make a good geometrical fit. This binding reaction causes the lymphocyte whose receptor has been selected to activate other plasma cells to produce more antibody with the same receptor geometry. (I. Roitt, *Essential Immunology*[7] [Oxford 1991] fig. 2:10)

similar invaders in the future (fig. 28). Different parts of the foreign invader may trigger different B-lymphocytes to produce a range of antibodies, all of which will react with the original antigen.[202] This is the molecular basis of the resistance to disease.

DETECTION METHODS

For immunochemical work, the molecule to be identified or quantified (e.g., the human bone protein osteocalcin) is injected into the bloodstream of a host animal such as a rabbit and becomes the antigen. This stimulates the rabbit's immune system to produce antibodies to human osteocalcin (described as rabbit anti-human osteocalcin). These antibodies can be collected and purified, and are then used to bind with human osteocalcin wherever it may be encountered (for instance, in mixed protein extracted from archaeological bone).

In order to be certain that this binding has taken place, it is important to be able to demonstrate the existence of the antibody-antigen complex thus formed. This can be done by a variety of methods, but in archaeological immunochemistry, two main techniques have been used: radiolabeling, known as RIA (radioimmunoassay, using a low activity radioactive compound attached to the antibody), or enzyme labeling. The latter method (ELISA—Enzyme-Linked Immunosorbant Assay) is now becoming more popular because it does not require the use of radioactive material. It has the disadvantage, however, that a further step is needed, usually the addition of another chemical that will change color when it comes in contact with the enzyme. The amount of antigen detected can then be quantified because the depth of color change is proportional to the amount of antibody-antigen complex produced. One problem posed by archaeological material is that extracted solutions are often colored by humic compounds from the soil, which may mask the color change.

Both these detection systems can be used in conjunction with gel separation techniques, in which the molecules extracted are separated according to size and electric charge (electrophoresis), followed by transfer onto a suitable supporting membrane (blotting) prior to detection. This gives increased

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[202] G.J.V. Nossal, "Life, Death and the Immune System," *Scientific American* 269:3 (1993) 21–29.

specificity, since the molecular weight range of the antigen can also be measured (dot-blotting or Western blot).

ARCHAEOLOGICAL APPLICATIONS

The principal use of immunochemistry in archaeology has been to demonstrate the presence of a particular biological compound in material from an archaeological context. A typical example would be the detection of apohaemoglobin (a blood protein) in archaeological bone. To date, much of this work has largely been directed toward discovering how long biomolecules can survive in an immunologically recognizable form. So far, the direct archaeological benefits of this work have yet to be seen, but hold some promise for the detection of diseases that leave no lesions in bony tissue.

In general, the applications of immunochemistry to palaeobiology and archaeology fall into the following three broad categories:

1) The demonstration of protein survival in "dinosaurs" and other fossil species. More specifically, the degree of affinity between modern antibodies and extracted fossil antigens has allowed a phylogenetic study of certain fossil and modern animals, such as mammoth, mastodon, and modern elephants or seals and terrestrial carnivores.[203] Archaeologically more relevant are the studies of Neolithic and Bronze Age equids,[204] and the preliminary work on Neanderthal, *Homo erectus*, *Australopithicus robustus*, and Cro-Magnon man.[205] The assumption is that the affinity or degree of binding between an antibody raised against a particular protein from the modern species and an ancient antigen (the comparable protein extracted from the ancient sample) is a measure of the genetic similarity between the two species. Arguably, a better measure of this may now be provided by DNA homologies.

2) The detection of proteins in archaeological human bone and/or mummified tissue. As noted above, this research at present is largely driven by curiosity about the length of time that biomolecules can survive in archaeological human tissue from a variety of contexts. Proteins in human bone that have been studied include apohaemoglobin[206] (which, together with iron, is responsible for oxygen transport in the bloodstream) and albumin[207] (the most abundant dissolved protein in serum).

Complications arise with the immunochemical detection of degraded protein (see below), but potentially this approach could be used for the diagnosis of a range of diseases that are not currently visible in the archaeological record.

3) A third area of application is much more controversial—the use of immunochemical tests to identify blood residue proteins both on stone tools and as a pigment in rock art. The subject was first investigated in 1983, when T. Loy[208] identified the species of origin of blood residues on stone tool surfaces from recrystallized haemoglobin, after confirming the presence of blood using test-strips. The latter are used as a very presumptive screening method for the detection of albumin and apohaemoglobin in fresh urine samples. Fresh samples are required, since, after one day, there is contamination by the products of bacterial metabolism that can give false positives. Myoglobin and chlorophyll, along with other porphyrin-ring containing substances, also give false positives.[209] Because of the caution with which dried blood residues are treated by forensic scientists and because it was unclear whether Loy's samples were uncontaminated, his results were greeted rather skeptically. Further work by Loy and others has now proved beyond a reasonable doubt that recognizable proteins can indeed survive for long periods, although a number of investigators still express concern about the techniques used in some of these blood residue studies.[210] The oldest reported blood residue dates to 90,000 years ago, from Tabun Cave in Israel.[211]

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[203] J.M. Lowenstein and G. Scheuenstuhl, "Immunological Methods in Molecular Paleontology," *Philosophical Transactions of the Royal Society of London* B 333 (1991) 375–80.

[204] A.S. Gilbert, J.M. Lowenstein, and B.C. Hesse, "Biochemical Differentiation of Archaeological Equid Remains: Lessons from a First Attempt," *JFA* 17 (1990) 39–48.

[205] J.M. Lowenstein, "Immunological Reactions from Fossil Material," *Philosophical Transactions of the Royal Society of London* B 292 (1981) 143–49.

[206] P.R. Smith and M.T. Wilson, "Detection of Haemoglobin in Human Skeletal Remains using ELISA," *JAS* 17 (1990) 255–68.

[207] C. Cattaneo, K. Gelsthorpe, P. Phillips, and R.J. Sokal, "Reliable Identification of Human Albumin in Ancient Bone using ELISA and Monoclonal Antibodies," *American Journal of Physical Anthropology* 87 (1992) 365–72.

[208] T.H. Loy, "Prehistoric Blood Residues: Detection on Stone Tool Surfaces and Identification of Species of Origin," *Science* 220 (1983) 1269–71.

[209] R.E. Gaensslen, P.J. Desio, and H.C. Lee, "Genetic-Marker Systems: Individualization of Blood and Body Fluids," in G. Davies ed., *Forensic Science* (Washington, D.C. 1986) 209–40.

[210] See A.M. Child and A.M. Pollard, "A Review of the Applications of Immunochemistry to Archaeological Bone," *JAS* 19 (1992) 39–47, with references.

[211] T.H. Loy and B.L. Hardy, "Blood Residue Analysis of 90,000-year-old Stone Tools from Tabun Cave, Israel," *Antiquity* 66 (1992) 24–35.

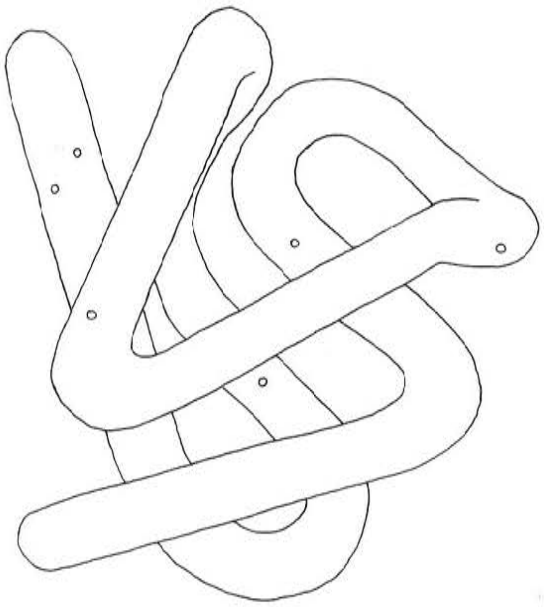

Fig. 29. Schematic drawing of a folded protein molecule showing how the epitopic region recognized by a single antibody (marked by the symbol o) is discontinuous throughout the protein chain as a whole, depending strongly on the exact three-dimensional shape of the chain. If the protein is degraded, it is unlikely that the individual components of the epitopic region, even if they are all still present, will retain the same geometry, and therefore the chances of recognition occurring are drastically reduced. (A.M. Child and A.M. Pollard, *JAS* 19 [1992] fig. 1)

THE PROBLEM OF DEGRADED PROTEIN

Although antibody-antigen recognition is based on a three-dimensional geometrical "matching," it actually involves only a small region of the antigen. In other words, even in a relatively large molecule such as apohaemoglobin, recognition involves only a very small fraction of the total structure, which is known as the epitope (fig. 29). The latter may be either a specific short sequence of the amino acid chain that makes up the protein, or it may be a number of nonsequential parts of the chain that just happen to lie together in space because of the three-dimensional nature of the molecule. An antigen may have several epitopes, which is why one antigen may induce many different antibodies.

Given that these recognition sites are only a small part of the total structure, it follows that incomplete (i.e., degraded) proteins may still be recognized by an antibody raised against the complete molecule, provided that the particular epitope is intact. Conversely, and more likely, it also follows that a partially degraded molecule may have lost the particular sequence or shape that the antibody recognizes, and therefore go undetected. This is a problem peculiar to archaeological and palaeobiological proteins, and gives rise to a number of possibilities that must be considered. If antibodies are raised against intact protein, what are the chances of missing slightly degraded proteins? Alternatively, antibodies raised against degraded proteins are likely to have a high affinity for proteins other than those against which they were raised (i.e., they give false positives).[212] These problems, when coupled with those of contamination, which is a characteristic of any biological study of archaeological material, make the immunochemical study of prehistoric human bone a challenging field.[213]

MUMMIFIED TISSUE AS A CASE STUDY

Although most archaeological human remains are skeletonized, there is a whole class of mummified tissue that is characterized by the survival of a significant amount of soft tissue, which is of great interest to the palaeobiologist and palaeoserologist. Mummies—both natural and artificial—have now been extensively studied, and are probably the most fruitful area for the application of immunochemical techniques.[214] It is here that immunochemical detection of protein, in addition to providing information about the survival of particular proteins, can also be expected to give evidence of infectious diseases. Antibodies to disease are themselves proteins (called immunoglobulins), which, if produced by the host *in vivo* may survive in mummified tissue, and therefore be detectable by immunochemical methods.

The amino acids that link together to form proteins can also be studied, either individually in providing a potential dating technique (known as amino acid racemization[215]) or collectively for confirming the identity of proteins by matching their amino acid profile with modern standards. Another class of biomolecules, the lipids (fats), are potential

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[212] I.A. Wilson, D.H. Haft, E.D. Getzoff, J.A. Tainer, R.A. Lerner, and S. Brenner, "Identical Short Peptide Sequences in Unrelated Proteins Can Have Different Conformations: A Testing Ground for Theories of Immune Recognition," *Proceedings of the National Academy of Sciences of the USA* 82 (1985) 5255–59.

[213] Child and Pollard (supra n. 210).

[214] R.A. Borraco, "Paleobiochemistry," in A. Cockburn and E. Cockburn eds., *Mummies, Disease and Ancient Culture* (Cambridge 1980) 312–26.

[215] P.M. Masters, "Amino Acid Racemisation Dating—A Review," in M.R. Zimmerman and J.L. Angel eds., *Dating and Age Determination of Biological Materials* (London 1986) 39–58.

sources of information about tissue integrity, diet, lifestyle, and evidence of disease.

Palaeoserology, in particular the study of ancient blood groups, is reported to work best when soft tissue is preserved.[216] Since blood groups, as defined by the ABO antigens, can be determined from cells extracted from bone, hair, skin, or muscle, as well as blood cells, there have naturally been a number of studies in which blood grouping has been attempted on mummies.[217] Standard tests for free ABO antigens have yielded poor results, but tests adapted for tissues devoid of blood are claimed to have given adequate results.[218] These data have been used to study relationships between living and prehistoric populations in the Aleutian Islands, southwestern United States, Peru, and Chile. More recently, however, it has been realized that blood grouping on material extracted from soil is extremely dubious due to the ubiquity of interfering material, and it is not now recommended.[219] Again, it would appear that if population genetics are required, the best approach is now to use DNA homologies. Potentially, therefore, it would seem that useful palaeoanthropological information can be obtained from the palaeobiology of mummified tissue, although most authors stress that this must be used in conjunction with other information.

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Palaeogenetics: DNA for the Archaeologist

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In 1981, Chinese scientists reported the extraction of nucleic acids, the genetic material of all living cells, from a body found in the Changsa Han tomb.[220] Despite the considerable implications of the discovery, the result was hardly recognized at the time. Four years would pass before scientists in the Western hemisphere presented similar results from this new field of science, which now is materializing in an interdisciplinary space between archaeology, molecular biology, genetics, biological anthropology, palaeozoology, palaeobotany, and palaeontology. For reasons mentioned below, the discipline is here called palaeogenetics, but other names have been applied to it, such as genetic archaeology, biomolecular archaeology, or simply molecular archaeology. The discovery of the method and its impact on archaeological science have been compared to that of radiocarbon dating, although the potential of reconstructing aspects of ancient biological life is more far-reaching than dating such remains. Thus far, most palaeogenetic research has been concentrated on the development of analytical methods. Considerable effort has also gone into finding the oldest genetic material. A weevil trapped in amber, which is dated to 120–135 million years B.P., has been reported, and plant remains in amber have also produced DNA.[221] Even if a very conservative estimate is assumed for the preservation of ancient DNA (5,000–10,000 years), these discoveries demonstrate that it can survive under special circumstances for much longer times.

GENERAL BACKGROUND

Organic life takes shape due to a coded record in DNA molecules (Deoxyribo-Nucleic Acid), which are located in the chromosomes of the cell nucleus. The four "building blocks" of DNA molecules are nu-

[216] Borraco (supra n. 214).

[217] R.L. Henry, "Paleoserology," in Cockburn and Cockburn (supra n. 214) 327–34.

[218] Borraco (supra n. 214).

[219] W.F. Rowe, "The ABO Grouping of Human Remains—A Review," in G.C. Llewellyn and C.E. O'Rear eds., *Biodeterioration 6* (Proceedings of the 6th International Biodeterioration Symposium, Slough, Eng. 1984) 134–42.

[220] G.H. Wang and C.C. Lu, "Isolation and Identification of Nucleic Acids of Liver from a Corpse from the Changsa Han Tomb," *Shen Wu Hua Hsueh Yu Shena Wu Li Chin Chan* 39 (1981) 70ff [Chinese].

[221] E.g., R.J. Cano, H.N. Polnar, N.J. Pieniazek, A. Acra, and G.O. Polnar, "Amplification and Sequencing of DNA from a 120–135-million-year-old Weevil," *Nature* 363 (1993) 536–38; H.N. Polnar, R.J. Cano, and G.O. Polnar, "DNA from an Extinct Plant," *Nature* 363 (1993) 677.

cleotides that are labeled A, T, C, and G according to their base contents (A = adenine, T = thymine, C = cytosine, and G = guanine). The nucleotides are joined in pairs (A–T and C–G) to form a long double helix, which through the interaction with RNA (Ribo-Nucleic Acid) determines and regulates the synthesizing of proteins in particular enzymes. A particular sequence of nucleotides, a gene, determines a specific protein. DNA molecules, which store the biological information, are transmitted through reproduction among individuals. Thus, all the inherited characteristics of the individual (the genotype) can be described by its DNA. Defects or changes in the genes occur (e.g., by ionizing radiation), leading to mutations and inherited diseases such as cystic fibrosis and hemophilia. The evolution of a domesticated plant or animal species is due to human exploitation and selection of individuals or races that have optimal genetic characteristics.

At the termination of life, enzymatic activity normally initiates destruction of DNA and RNA. Under one set of extraordinary conditions, however, caused either by nature itself or by human intent, some of the nucleic acid in cells or tissue may survive by the process of mummification.

ARCHAEOLOGICAL APPLICATIONS AND PROCEDURES

An early attempt to extract and characterize ancient DNA was made on mummified tissue from an extinct zebra species, the quagga.[222] The successful extraction of DNA from an Egyptian mummy soon followed.[223] The results showed that it was possible to extract small segments of the genome. An obstacle in these pioneering efforts was to prove the authenticity of the DNA extracted from the specimen. Mummies in museums have often been handled by a number of individuals, and just a single cell from a conservator or scientist may contaminate the sample. This problem is greatly magnified if the amplification method known as PCR (Polymerase Chain Reaction) is used. A single sequence of DNA, whether targeted or a result of contamination, will be multiplied to several million copies by this technique. On the other hand, the strength of the method in generating ancient DNA is apparent. In theory, one surviving ancient molecule or segment is sufficient for characterizing some biological aspect of a plant, animal, or human individual (e.g., part of a Y-chromosomal DNA-segment can establish that a human individual is male).

Radiocarbon dating of ancient DNA assumes that contamination factors have been excluded. For museum specimens, contamination from handling can be ignored when non-human animal or plant species are being tested, since specific non-human DNA sequences are targeted. For human samples, contamination must be avoided or removed (e.g., by sampling from body regions that have never been exposed or handled by humans, or by cleaning the exposed surfaces of the samples).

Although the discovery of ancient DNA from mummy tissue in museum collections was groundbreaking, its archaeological applications are restricted. Only a finite number of mummies are available for analyses. Therefore, attempts were made to extract DNA from ancient bone and teeth. In 1989 and 1990, two research groups independently reported successful extraction of human DNA from bones.[224] Because of its very broad applicability to human and animal bone remains, this discovery has important implications for future archaeological research.

Since the discipline of palaeogenetics is barely 10 years old, its archaeological accomplishments have been limited. There are a few instances of sex determination and ethnic characterization of human archaeological material.[225] Biological topics, such as taxonomy and general evolutionary theory, have generally received the most attention. Egyptian mummies have already been mentioned. Broader-based, more systematic research programs are now in progress.[226] The prehistoric and historical populations of central Italy and Spain are being studied using

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[222] R.G. Higuchi, B. Bowman, M. Freiberger, O.A. Ryder, and A.C. Wilson, "DNA Sequence from the Quagga, an Extinct Member of the Horse Family," *Nature* 312 (1984) 282–84.

[223] S. Pääbo, "Molecular Cloning of Ancient Egyptian Mummy DNA," *Nature* 314 (1985) 644–45; for a recent overview by the same author, see "Ancient DNA," *Scientific American* 269:5 (1993) 86–92.

[224] E.g., E. Hagelberg, B. Sykes, and R. Hedges, "Ancient Bone DNA Amplified," *Nature* 342 (1989) 485; I. Thuesen and J. Engberg, "Recovery and Analysis of Human Genetic Material from Mummified Tissue and Bone," *JAS* 17 (1990) 679–89.

[225] E.g., S. Hummel and B. Herrmann, "Y-Chromosome-Specific DNA Amplified in Ancient Human Bone," *Naturwissenschaften* 78 (1991) 266–67; H. Nielsen, J. Engberg, and I. Thuesen, "Frozen Samples: DNA from Arctic Human Burials," in B. Herrmann and S. Hummel eds., *Ancient DNA* (New York 1993) 119–37.

[226] See R.K. Wayne and A. Cooper eds., *Ancient DNA Newsletter*, Institute of Zoology, Regent's Park, London NW1 4RY, England.

palaeogenetic methods.[227] A multidisciplinary project has been initiated for the Guanche mummies of the Canary Islands.[228] Successful extractions of DNA from carbonized plant remains have been reported for ancient Jordan (Tell es-Sa'idiyeh).[229] Our palaeogenetic research group has been engaged in pilot studies since 1986 to adapt palaeogenetic methods to archaeological issues, both in analyzing museum specimens and in developing appropriate field methods.[230]

The scientific procedure begins with the formulation of an archaeological problem that can conceivably be answered on the basis of genetic information. The individual is sampled from a well-preserved part. For example, for a human skeleton, a piece of a femur or a tooth is excellent. Any contamination must be avoided. The DNA in the sample is then extracted according to protocols, which may differ depending on the type of tissue, skin, bone, etc.[231] If the extracted DNA is damaged, it can be repaired by other procedures to obtain adequate ancient DNA, i.e., DNA that can be routinely handled by molecular biological procedures. Sometimes the extracted DNA contains substances that inhibit the PCR amplification; this problem can be solved by further purification procedures.

The next step in the analysis is genetic characterization of the extracted DNA, which requires knowledge of the particular sequences that characterize sex, biological kinship and ethnicity, and species variation or defects (such as inherited diseases). For determination of human sex, the X- and Y-chromosomes are obvious targets. For species variation, particular highly variable regions of the genome are relevant. In that regard, particular attention has been directed to so-called mitochondrial DNA (mtDNA). These DNA molecules are located in organelles (mitochondria) outside the cell nucleus, and are inherited only maternally.

The targeted DNA sequence from the sample is amplified by PCR. The nucleotides of the PCR product are sequenced and compared to reference DNA sequences in order to establish the species and other biological characteristics. With these results, the archaeological problem has been resolved or must be reassessed for further research.

Fig. 30. Sampling of human remains for DNA analysis in the field in eastern Syria. A tooth, after being removed from a cranium, is placed in a tube with a DNA-extraction buffer.

A CASE STUDY FROM ANCIENT SYRIA

In 1990 and 1991, a Danish archaeological expedition excavated remains of a settlement and cemetery at Tell Mashnaqa in the middle Khabur River

[227] R. Mariani-Costantini and colleagues at the Institute of Pathology, Università Gabriele D'Annunzio, Chieti, Italy; and A. Perez-Pérez and colleagues at the Secc. Antropologia, Universidad de Barcelona, Spain.

[228] A.C. Aufderheide (Department of Pathology, University of Minnesota, Duluth), C. Rodríguez Martín (Museo arqueológico de Tenerife, Santa Cruz, Canary Islands), and colleagues. DNA analyses have also been carried out by P. Rogan (University Hospital, Hershey, Penn.), and W. Salo (University of Minnesota, Duluth).

[229] T.A. Brown and K.A. Brown, "Ancient DNA and the Archaeologist," *Antiquity* 66 (1992) 10–23.

[230] I coordinate a palaeogenetic research group at the University of Copenhagen and the National Museum in Denmark. Many of the ideas and the case study presented here are based on the work of this group, whose members include Henrik Nielsen (Department of Biochemistry), Søren Nørby (Department of Forensic Genetics), Jens Peder Hart Hansen (Laboratory for Biological Anthropology), all at the University of Copenhagen, and Bent Aaby, who is in the Science Unit of the National Museum.

[231] See B. Herrmann and S. Hummel eds., *Ancient DNA* (New York 1993).

region, Syria.[232] The finds have been radiocarbon dated by accelerator mass spectrometry (AMS) to ca. 5000 B.C. Palaeogenetic methods were employed to develop field methods and to obtain culture-historical information. How long would DNA in fragile 7,000-year-old human bones be preserved in a hot and mostly dry environment? If preserved, palaeogenetic information on sex and ethnicity might be obtained.

In 1990, the samples of bones, which were brought back to the laboratory in Copenhagen, gave negative results for DNA, and the observed chemical reactions indicated that destructive enzymatic activities might have been triggered by exposure of the bones to air and light. Therefore, a procedure was developed in the next field season to reduce the risk of post-exposure degradation and modern contamination. Burials were carefully located before bone material was exposed. A team of scientists (including molecular biologists and physical and dental anthropologists) excavated the human remains. The position of the body and large bones were identified before the skeleton was completely exposed. A few centimeters of bone were removed and placed in tubes with DNA-extraction buffers as soon as the skeleton was uncovered. Gloves were worn to avoid contamination. Teeth were especially important, since it is believed that DNA in the interior, sealed environment of the tooth might be better preserved. After recording and photographing, a tooth would be pulled out from the jaw and placed in a tube with a DNA-extraction buffer (fig. 30). After a few hours, DNA-extraction was initiated in the camp headquarters.

This routine produced a large series of samples from the burials. Although the laboratory analyses are still in progress, the preliminary results indicate that specific palaeogenetic routines can be carried out in the field, even under the difficult and trying conditions of the east Syrian desert.

FUTURE PERSPECTIVES

The application of palaeogenetics to archaeological remains depends upon the close collaboration of archaeologists and geneticists. Such research promises to contribute significantly to the reconstruction of past human life and environmental adaptation. Determination of human sex, biological ethnicity, and kinship are realistic objectives given the rapidly growing knowledge of the human genome. For other animal and plant species, ancient DNA analysis should contribute significantly to traditional morphological identification. Since DNA from microorganisms will also eventually be isolated and identified, new perspectives on inherited and infectious diseases, the fermentation of ancient foods and beverages, etc., should emerge.

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Archaeological Conservation

CATHERINE SEASE

Every civilization has had people repairing and conserving objects of cultural importance. It is not uncommon, but always fascinating, to excavate artifacts that were repaired in antiquity. The conservation of archaeological material as we know it has slowly developed into a discipline over the past 200 years.[233] In the 16th, 17th, and 18th centuries, much cleaning, repairing, and restoring of antiquities was done empirically by craftsmen or archaeologists and was not based on scientific principles. Heavy-handed restorations led to the alteration and sometimes destruction of a considerable amount of excavated material. By the early 19th century, reaction by archaeologists to these restorations precipitated a change resulting in a preference for antiquities in their original condition. At this time, publications also began to appear that dealt with the treatment of antiquities,[234] as well as the analysis of the materials of which they were made.

In 1888, the Royal Museums of Berlin established their Chemical Laboratory, and Friedrich Rathgen, its first director, became the first scientist hired to

[232] See, e.g., I. Thuesen, "Tell Mashnaqa," in H. Weiss, "Archaeology in Syria," *AJA* 95 (1991) 691–92 and *AJA* 97 (1993) 111–12.

[233] N.L. Caldararo, "An Outline History of Conservation in Archaeology and Anthropology as Presented through Its Publications," *Journal of the American Institute for Conservation* 26 (1987) 85–104.

[234] H.G. Bennet, "An Account of the Ancient Rolls of Papyrus Discovered at Herculaneum and the Method Employed to Unroll Them," *Archaeologica* 15 (1806) 114–17.

Fig. 31. Conservator in the process of consolidating and lifting two onager skeletons from a burial in Iraq

work in a museum laboratory. He recognized the need for a systematic approach to conservation and a scientific understanding of how and why artifacts deteriorate. Over his 39-year career, Rathgen was actively involved in developing and applying physical and chemical methods to the preservation of archaeological materials, and he thus played an important role in the development of archaeological conservation as a science and profession.[235] As similar laboratories were established at other museums, the number of scientists working on the conservation of artifacts grew.

At the same time, the literature pertaining to archaeological conservation grew. Rathgen's handbook, *Die Konservierung von Altertumsfunden* (Berlin) appeared in 1898; an English translation appeared in 1905 entitled *The Preservation of Antiquities: A Handbook for Curators* (Cambridge). This was followed in 1934 by the publication of Harold Plenderleith's *The Preservation of Antiquities*, which in its revised form (London 1971) has until recently been a standard reference for English-speaking conservators.

Most early conservation treatment took place in laboratories, and field conservation consisted predominantly of rudimentary techniques to remove excavated material safely from the ground and to a laboratory where it could be studied. In 1888, Flinders Petrie published a short article in the *Archaeological Journal* (vol. 65, pp. 85–89) in which he described treatment methods he employed in the field on freshly excavated material. Today, three manuals and numerous publications provide the archaeologist with basic field conservation techniques.[236]

In the early years, no formal training for conservators existed. Conservators received their training through an apprenticeship system working in museum laboratories. In 1957, the Institute of Archaeology, University of London, established the first university course in archaeological conservation.

Archaeological conservators today are highly trained specialists with a broad knowledge of all materials found on excavations. Ancillary disciplines, including archaeology, materials science, chemistry, ancient technology, and art history, are important parts of the conservator's training. Conservators need to understand the different materials from which artifacts are made and their chemical and physical structures. By understanding how these materials deteriorate and under what conditions, conservators are able to treat artifacts to prevent further deteri-

[235] I. Gilberg, "Friedrich Rathgen: The Father of Modern Archaeological Conservation," *Journal of the American Institute for Conservation* 26 (1987) 105–20.

[236] C. Sease, *A Conservation Manual for the Field Archaeologist*[2] (Archaeological Research Tools 4, Los Angeles 1992); D. Watkinson ed., *First Aid For Finds* (London 1987); and K. Singley, *The Conservation of Archeological Artifacts from Freshwater Environments* (South Haven, Mich. 1988).

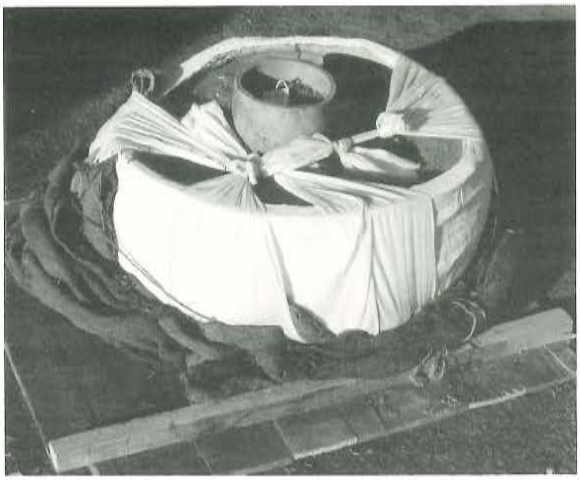

Fig. 32. Heavy, fragile pottery vessels, here examples from an excavation in Iraq, can be bandaged and moved to the laboratory for careful removal of soil, consolidation, and reconstruction

oration from taking place. Excellent manual skills and a sensitivity for objects and materials are also prerequisites for a conservator.

In the field, a conservator is typically responsible for cleaning all artifacts, stabilizing metals and fugitive paints, piecing together broken objects, and lifting delicate objects out of the ground (figs. 31–32). In some instances, treatment can be considered merely first-aid measures for safely excavating objects and shipping them to a conservation facility where they can be examined. A series of lifting techniques has been developed over the years for this purpose. More and more frequently, however, due to laws governing the removal of material from the country of origin, the only conservation treatment that artifacts receive will be that done in the field. This places greater pressure on the conservator to treat artifacts more fully in the field, so that the maximum information can be retrieved from each object (see fig. 33), research carried out, and publication drawings and photographs made before the artifacts disappear into museum storerooms.

Documentation is an important part of any conservation treatment. Conservators maintain written and photographic records detailing the condition of an object before and after treatment, the various steps in its treatment, the materials used, and any observations that might be of interest to the archaeologist, conservator, and other scientists who may subsequently work on and study the object. For example, textiles and other organic materials are frequently preserved only in the corrosion products of associated metal artifacts (fig. 33). A trained eye

Fig. 33. Detail of an Anglo-Saxon sword. Wood, leather, and fleece have been preserved by the iron corrosion products, and could easily have been lost by injudicious cleaning.

and careful cleaning techniques enable a conservator to bring to light evidence that could easily be destroyed by inexperienced hands.

Conservators can also help in planning and implementing the storage of artifacts, of particular importance for multiseason excavations that provide on-site storage for years before artifacts go to the local or national museum. By assuring optimum storage conditions, particularly for metal artifacts, the long-term preservation of the excavated material is greatly increased. Conservators can also help pack objects safely to ensure their safe transport whether to the local museum or back to a laboratory or research facility in another country. Taking time and care over the packing of artifacts can mean the difference between their survival or destruction.

In addition to their knowledge of conservation, conservators bring additional expertise to an excavation. Experience working on known materials frequently enables the conservator to identify the ma-

terials from which objects are made. Sometimes this information can be of importance to the archaeologist when exotic materials unusual to the site are found. For example, at a site on Crete, material that was first labeled as fine ware ceramics was eventually identified by the author as fragments of ostrich eggshell.

A knowledge of ancient manufacturing processes frequently helps a conservator make observations about objects that other members of the team cannot. In cleaning an object, the conservator is the first person in perhaps thousands of years to examine it carefully, noting details of manufacture and use that add to the information the object reveals.

A conservator may be called upon to make casts or impressions of objects to aid in their study. For example, cylinder seals or coins cannot usually be taken out of a country for study. Rollings of the seals or plaster casts of the coins, however, often offer a more cost-effective means of studying this material. Numismatists also often prefer to publish photographs of coin casts, as they frequently show more detail than photographs of the coins themselves.

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