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PRECIOUS OPAL FROM JAVA

Gemmological properties, micro- and nano-structures

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ABSTRACT

Precious Javanese opal or kalimaya, as it is called by the locals, has been mined in Central Banten, West Java, Indonesia, since 1970. Early January 2006, the four authors, Tay Thye Sun, Mahardi Paramita, We Weng Kang and Kumala Wijaya visited eight opal mining pits near the Cilayang village, Curuk Bitung District, Lebak County (between 106° to 106° 50 East and 6° 50' to 7° 0' South). At Cilayang, one pit was in operation at the time. Cilayang produces white, brown, dark brown and jelly opal. Black opal is mined in other nearby gem-pits near the villages of Cikelurahan, Cimelingping and Ciguriman.

Key-words: Opal, volcanic, Indonesian, Java, Banten, hydrophane, kalimaya

The geological basement of the opal-bearing region is basically constituted of a mixture of volcanoclastic rocks, i.e. pumaceous tuffs and volcanic breccias, sandstones and clay beds originating from earlier (an older) island arc volcanism on Java. The opal-bearing *Genteng* deposits have been determined to be of Upper Miocene to Lower Pliocene age, about 4 to 7 million years old.

Thirty (30) samples were examined with basic gemological methods. Results are consistent with earlier data. The R.I. ranges from 1.43 to 1.45, and the S.G. from 1.98 to 2.02. Under long wave ultraviolet radiation kalimaya is inert to weak chalky blue with sometimes some weak orange around the edges, while under shortwave ultraviolet radiation it is generally inert with sometimes a very faint blue fluorescence.

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The Javanese opal tends to have tube-like inclusions with some cavities filled with clay minerals. White patches of silica-like material, whitish fissures and smokey brown veins are present in the opal. Some severe fissures caused the opal to break up easily and as a result the local miners often apply polymer coatings to prevent further crazing. Blue ink is sometimes also applied at the back of the opal to enhance the blue colour of the opal.

Seven samples of white and yellow opal were examined using X-Ray Diffraction (XRD), which yielded a mixture of broadened peaks corresponding to α-tridymite and α-cristobalite, leading to the nomenclature opal CT, (cristobalite + tridymite). A detailed study of the micro- and nano-structures of the opals was conducted using a Scanning Electron Microscope (SEM) and Atomic Force Microscopy (AFM). SEM investigations show the typical regular array of nanograin lepispheres, as found in other play-of-color opal-CT around the world, e.g. from Mexico and Ethiopia. AFM topography scans show the surface of most opals consist of less-ordered silica spheres, but regions with intense play-of-light show very regular uniformly-sized sphere packing.

INTRODUCTION

Precious opal has for sometime been encountered in volcanoclastic rocks in the hilly landscape Southeast of the city of Rangkasbitung, Kabupaten Lebak, in the province of Banten, West Java (Figs.1 and 2). This gemstone is known locally as "kalimaya" meaning "river of illusion".

The presence of precious opal was first mentioned in the Annual Report of the Mining Department (Jaarboek van het Mijnwezen) dated 1936-1937. In the chapter on Geological Investigations, Useful Raw Materials (p.17), it

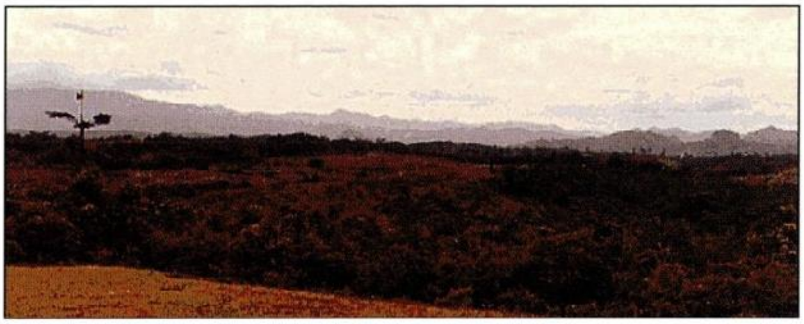


Fig.1: Banten Landscape, SE of Rangkasbitung, looking South in the direction of Gunung Endut (Photo C.E.S. Arps, 1981)

Fig.2: Map of Central Banten in West Java with the location of the opal fields (14 x 7 km) SE of Rangkasbitung

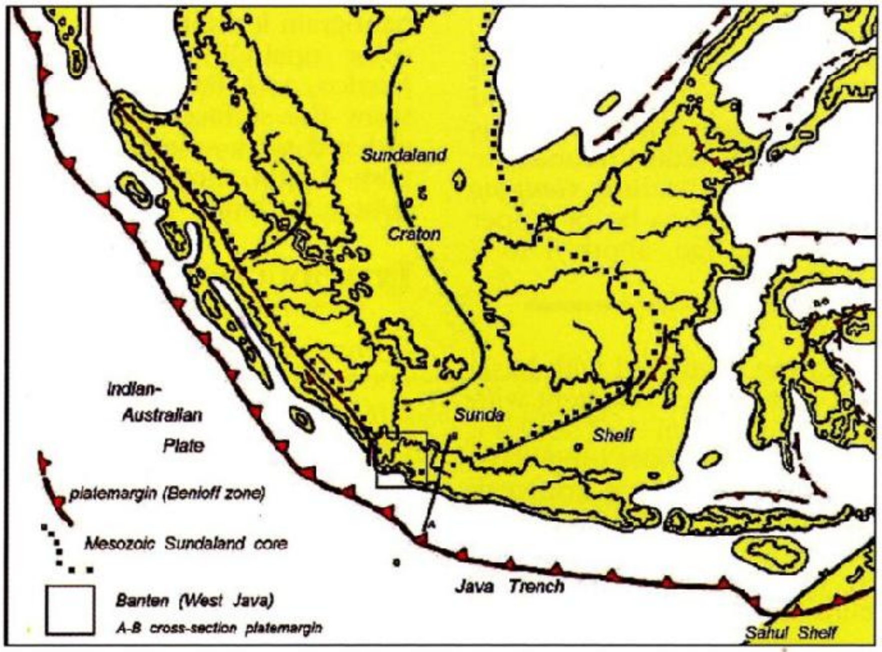


Fig.3: Sundaland craton, Southern part of the Eurasian crustal plate in contact with the Indian-Australian crustal plate. Banten is indicated (see also Fig.4); for cross-section A-B see Fig.4.

was stated *"In the Northeastern part of map nr.13 opalizing effects were repeatedly encountered in pumice tuffs. Precious opal of good quality, particularly the black variety with a good play-of-colours, have until now only been encountered in small amounts near Genteng. It is the first time that this kind of material has been encountered in the Dutch East Indies." **

(* translation from the Dutch language by co-author C.E.S. Arps).

In the years before World War II no serious efforts were undertaken to recover precious opals on an economic basis.

Geological outlines

Banten is located in the southern border zone of the Late Cretaceous Sundaland craton, as a part of the Sunda volcanic island arc that has been active since the Upper Mesozoic (Fig. 3). The history of the successive geological processes at the border of the EurAsian (convergent) continental plate margin, during the collision of Sundaland Craton with the Indian-Australian oceanic plate, is illustrated in the cross-sections of Fig.3.

This active plate margin, moving slightly southward, is characterized by a central geanticline. It is bordered by an extensive marine back-arc basin (Java Basin) to the North. To the South, it touches a fore-arc basin, accretionary complex including the Java Ridge and a trench (Java Trench) at the position where the crustal plates collide and move along each other.

The central, highest part of this structure is a relatively narrow E-W trending magmatic belt. Van Bemmelen (1949) structurally divided this zone in the northern Bogor Zone, a central depression zone (Bandung Zone) and the Southern Mountains (Fig. 4).

As part of the collision processes, magmatic rocks have intruded the plate margin or were extruded as lavas and volcanoclastic deposits of basaltic to andesitic and more acid (rhyolitic) composition, (arc magmatism). The volcanic rocks in the geanticlinal zone are repeatedly intercalated with sedimentary deposits of coastal, intermontane and intervolcanic nature (Hamilton, 1979). Volcanism started in the Early Tertiary but the majority of the volcanic rocks are of Quaternary age and volcanism has continued to the present time, e.g. the older Quaternary Gunung Karang, 1778 m, and Gunung Endut, 1286m, and the Gunung Salak, 2211m.

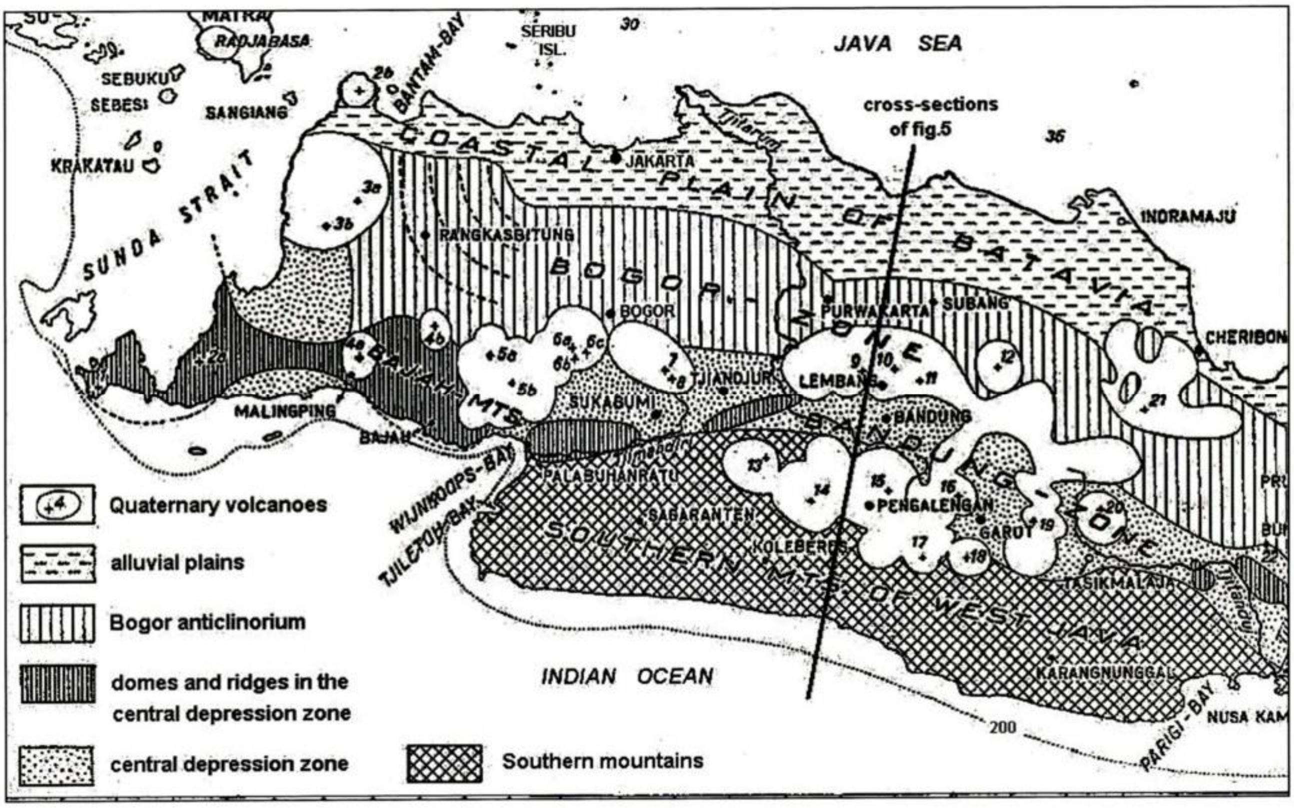
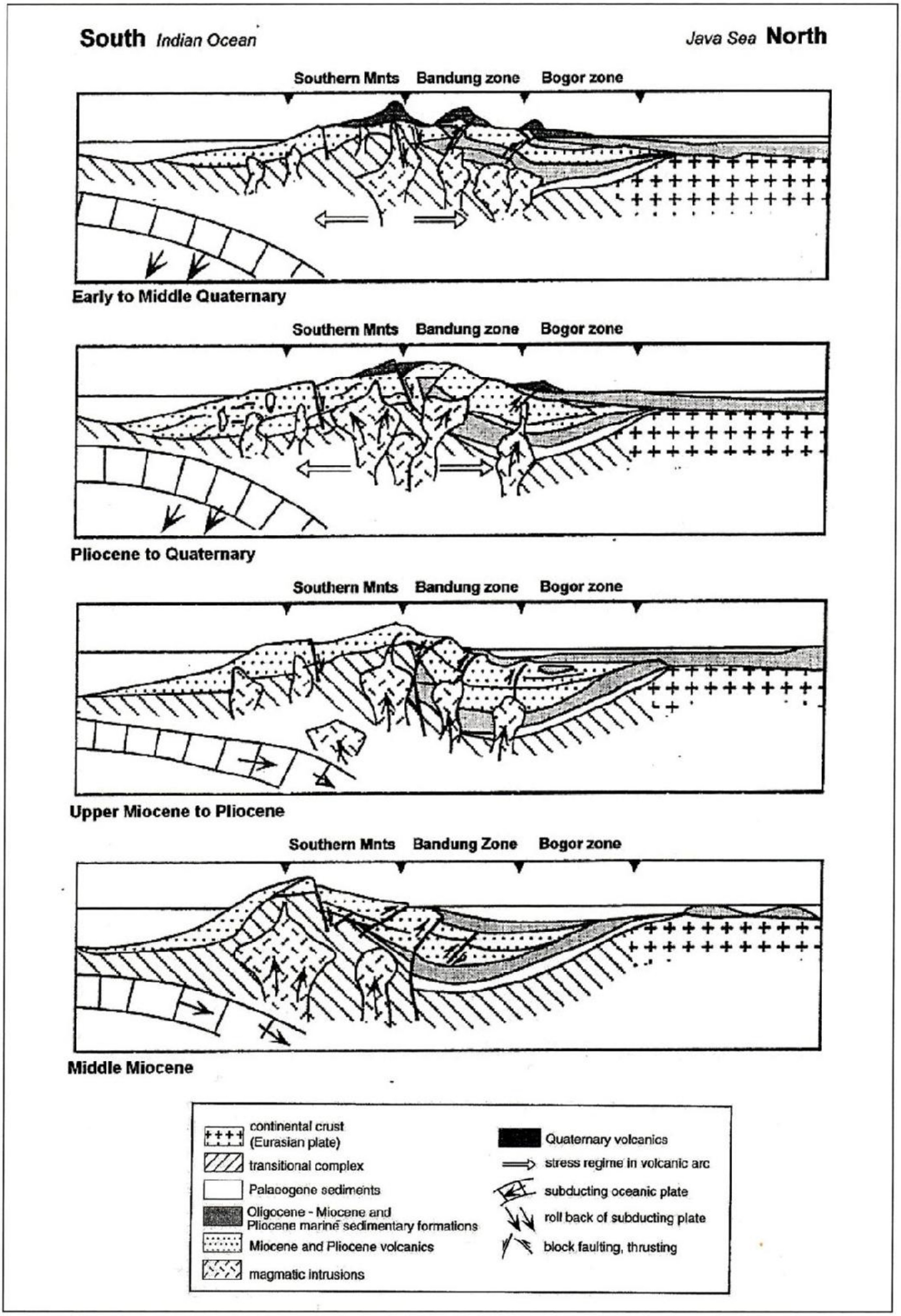


Fig.4: Structural division of West Java (van Bemmelen, 1949, p. 546) The area where opal-bearing rocks have been encountered is situated in the western extremity of the Bogor zone. Cross-sections A-B demonstrate the evolution of the plate-margin of the Sundaland Craton in West Java, in the Middle Miocene to Quaternary (illustrations from Dam, 1994).

Precious opal from Java



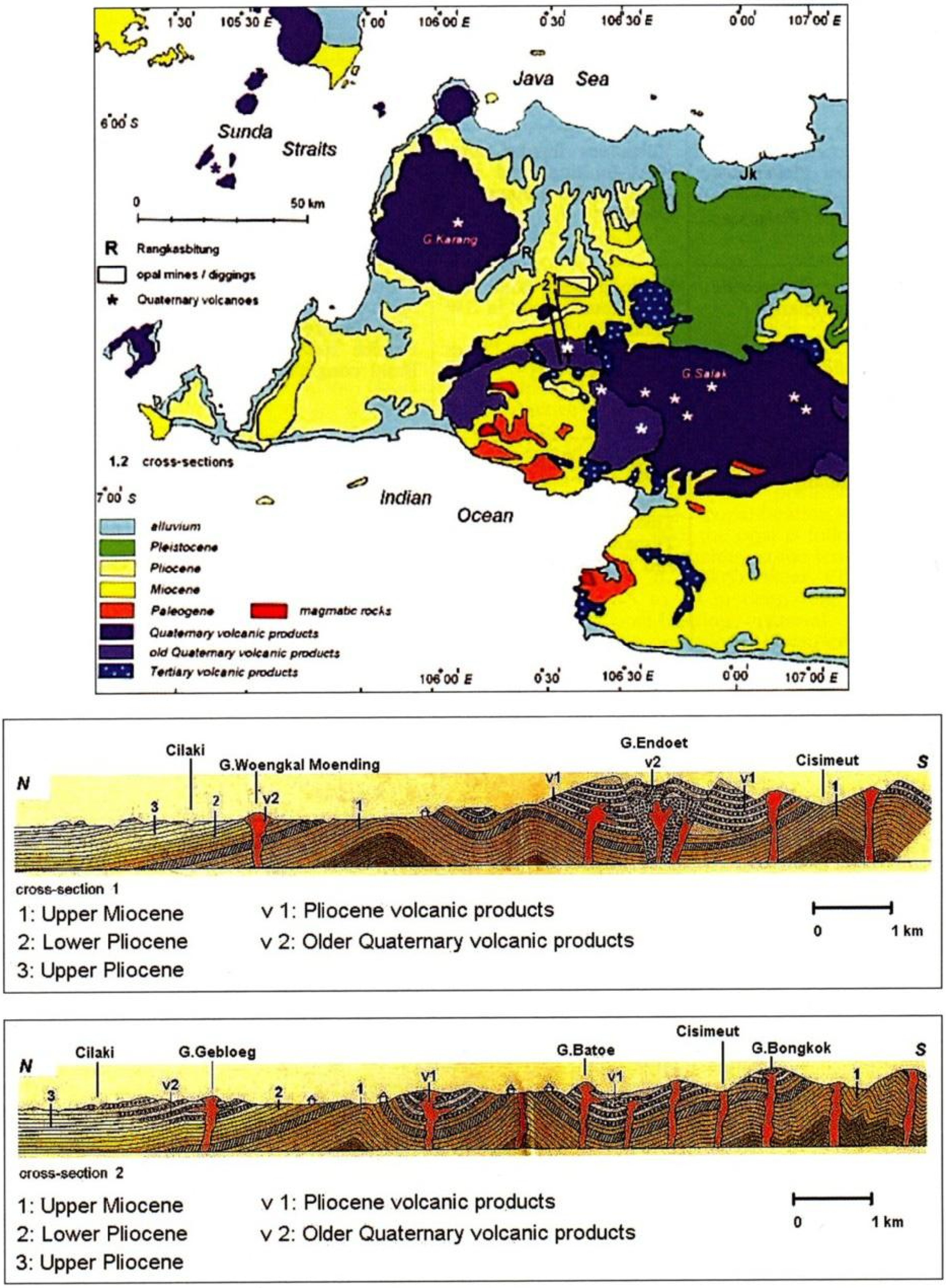


Fig.5: Geological sketchmap of the Western part of West Java,based mainly on the geological map of Jawa and Madura from the Geological Survey of Indonesia, 1977. The two illustrative cross-sections (after Van Es, 1915) through the Cenozoic Southeast of Rangkasbitung, in the western extremety of the Bogor Zone are added. The opal-bearing area near Gedong and Cilayang has also been indicated.

Stratigraphy of the Western part of the Bogor Zone in Central Banten, Java

Age and molluscan faunae	Stratigraphy	Composition	Thickness in metres
Holocene and Upper Pleistocene	Volcanoes formed after block-faulting and col-lapse of the Danau Complex		
Middle Pleistocene			
Lower Pleistocene (Bantamian)	Bodjong Beds (and part of Tjikeusik Beds in SW Bantam) (Upper part of the "Ban-tam tuffs")	Glauconitic, tuffaceous, more or less sandy marls, with limestone lenses Pumice tuffs Basal conglomerates	200
Upper Pliocene (Sondian)	Tjilegong Beds (pumice tuffs with marine inter-callations) and part of the Tjikeusik Beds = Tjimantjeuri Beds in SW and S Bantam	Pumice tuffs	50
		Pumice tuffs, rich in hornblende	60
		Pumice tuffs	40
		Pumice tuffs, rich in biotite	50
Middle Pliocene (Cheribonian)	Tjipatjar Beds	Upper part: tuffaceous glauconitic marls, clays, sandstones, andesitic breccias. Lower part: pumice tuffs (pisolitic)	400
Lower Pliocene	Genteng Beds	Pumice tuffs (pisolitic), rich in plant remains and silicified wood	730
Upper Miocene	dikes, lavas and tuffs	Intrusions of hornblende andesite	
Upper part of the Middle Miocene (Preanguerian)	Bodjongmanik Beds (*sensu stricto*) (= Tjida-dap Beds, East of Ban-tam)	Marls and clays with browncoal, tuff sand-stones, andesitic gravels In the upper part also pumice tuffs	
Lower to Middle Miocene (Rembangian)	Badui Beds (+ Lower Bodjongmanik Beds)	Limestones, marls, clay-shales Basal andesitic conglo-merates and sandstones	

Fig.6: Stratigraphic table of the Upper Cenozoic deposits in the Western part of the Bogor Zone in Central Banten, Java. (Jaarboek Mijnwezen, 1938; Van Bemmelen, 1949).

The geology of the Banten area was firstly mapped in detail by Van Es in 1915 in the region South of Rangkasbitung (Figs. 5 and 6). Some of the older eruptive centres are still visibly present and have been mapped, while others were later submerged (van Bemmelen, 1949). The general stratigraphy of the Upper Tertiary to Lower Quaternary in Central Banten was re-evaluated in the Annual Report of the Mining Department (Jaarboek van het Mijnwezen) of 1938 and later published by van Bemmelen in 1949, (Fig. 6). Here, the deposits are very much characterized by the presence of volcanoclastic layers, including many pumaceous tuffs. Certain altered porous tuff deposits of the Genteng beds turned out to be opal-bearing. Also silicified fossil wood was formed within these deposits and silicified tree trunks are locally abundant (Jaarboek Mijnwezen, 1938; Sujatmiko, et al., 2005). More detailed stratigraphical work was carried out for the Cilayang area by Adiman (1987) and for the Gedong area by A.S. Sulaeman (1991).

Presently, precious opals are recovered from a specific 30 cm to 2.5 m thick zone of strongly altered pumice tuff in the Genteng Beds formation. Larger fragments of unaltered to weakly altered opal-bearing host rock are rare, (see Sujatmiko, et al., 2005). According to van Bemmelen (1949, p.646) the age of the Genteng Beds is indicated as Upper Miocene to Early Pliocene (3.6 to ca. 7 MA), while Sujatmiko (2004) points to the age of Early Pliocene for the opal-bearing levels.

Mining of kalimaya

Mining of *kalimaya* opal is mainly concentrated Southeast of Rangkasbitung in the area between the rivers Ciberang, Cibeureum and Cidurian, in the neighborhood of the village of Gedong (Fig. 7). In more recent years mining has extended further to the East and West. The opals described in this study were recovered near the village of Cilayang, east of Gedong. Initially, attractive opals were occasionally found in river sediments and soils. Individual diggers have been (and still are) active in scattered locations along river beds and in shallow soils throughout the area (Figs. 8 and 9).

The first organized serious mining activities were started in the 1970's, but mining is still primitive. It is carried out during the dry season, roughly between March and October. More systematic and effective mining approaches entail digging shafts which may be as deep as 20 m, depending on the position of the economically attractive opal-bearing zone. When this zone is reached, the opal is followed along horizontal tunnels reaching some tens of metres (Sujatmiko, et al., 2005). Near Cilayang the diggings are 5 to 20 m deep (Fig. 10). The recovered opal-bearing material (from the relatively larger operations) is carried to nearby primitive 'plants' for washing, after which the attractive weathered and pitted opal fragments are picked-out and hand-sorted (Fig. 11). For more details about the mining the reader is referred to Sujatmiko's report (Sujatmiko, et al., 2005).

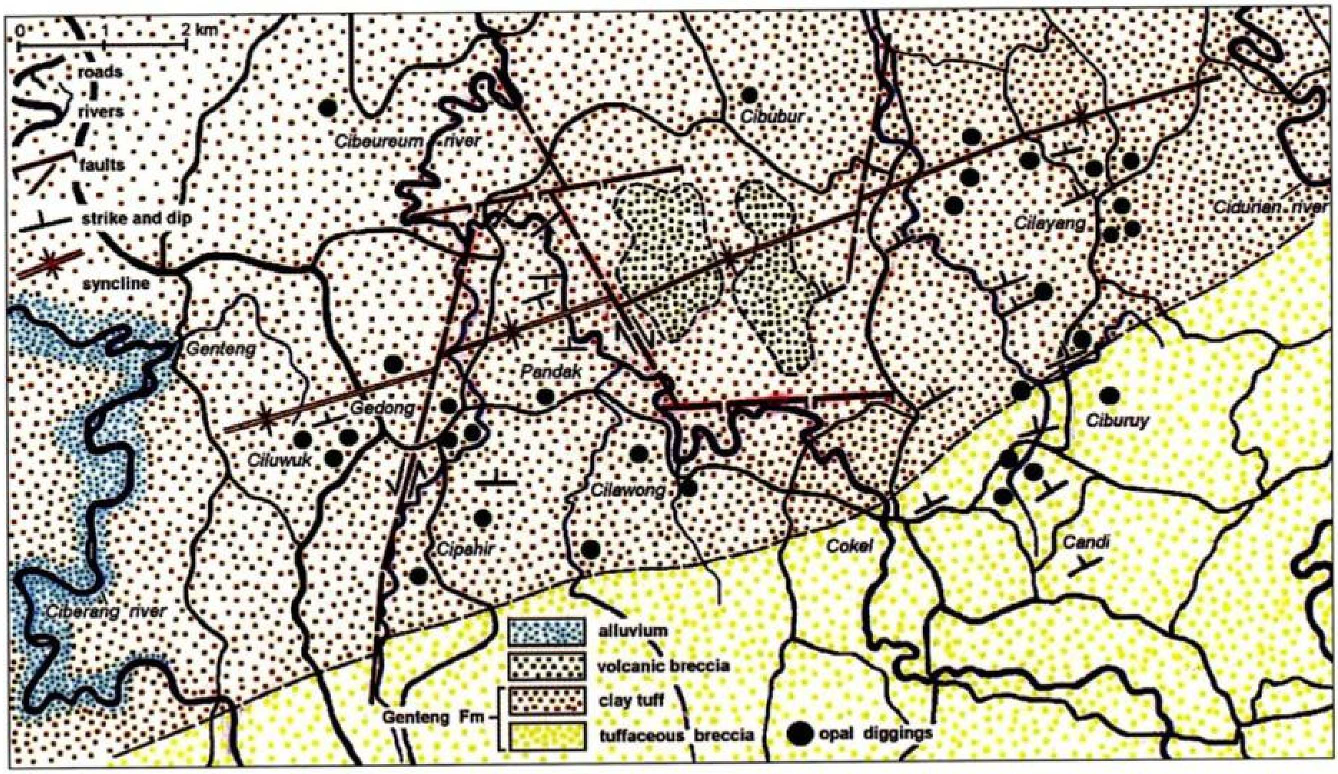


Fig 7: The mining area around the villages of Gedong and Cilayang (data mainly from Djatopet, et al., 1991).

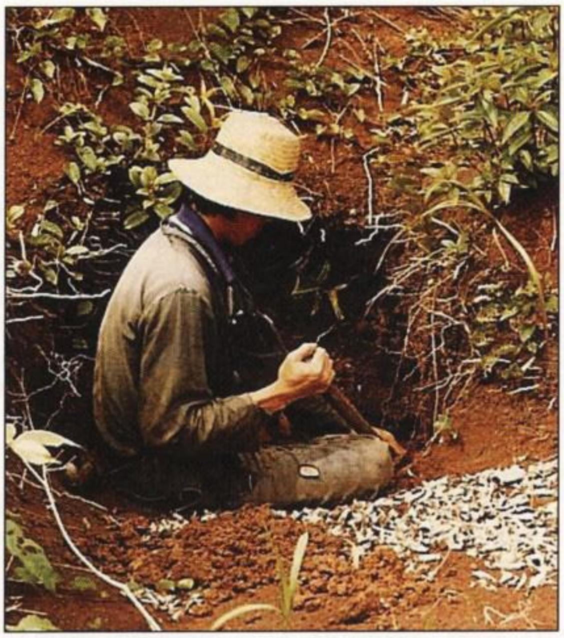


Fig. 8 Digging for opals in a kina plantation near Pasir Madang, SE of Rangkasbitung (Photo by C.E.S.Arps, 1981).

Fig. 9a Primitive shaft in the same area and wasteland after digging (Photo by C.E.S.Arps, 1981)

Fig. 9b Worked wasteland after digging (Photo by C.E.S.Arps, 1981)

Fig. 10 Mining for opal near Cilayang village (Photo by Tay, 2006.)

Fig. 11: Recovery of 'kalimaya' by hand-sorting from the pumice gravels (Photo by Tay, 2006)

Sample	J1	J2	J3	J4	J5	J6	J7	J8	J9
Weight	1.97 cts	2.01 cts	2.74 cts	3.76 cts	1.76 cts.	2.42 cts	6.02 cts	0.78 ct	1.14 cts

Sample	J10	J11	J12	J13	J14	J15	J16	J17	J18
Weight	1.50 cts	0.26 ct	2.84 cts	1.37 cts	0.97 ct	1.12 cts	1.32 ct	1.45 cts	1.11 cts

Fig. 12 Samples of 18 pieces of Java opal with weight from 0.26 to 6.02 ct and range of colour from black, white, orange, brown and milky white.

Gemmological Investigations

For the purpose of this study, twenty eight (28) Javanese opal samples (Fig. 12) with colours ranging from brown to yellow, white, and fifteen black samples were selected from a parcel of one kilogram of material. Fig. 12a & 12b are the range of colours of Japanese opal which were shown to us by some miners when the authors (TTS, MP, WWK and KW) were visiting one of the miners home. The selected pieces range in size from 0.26 to 6.02 carats with various shapes and degrees of diaphaneity, i.e. from transparent to opaque. Some colourless and orangy material are transparent and show good play-of-colour of reddish and orange flashes while the brown and black opal displays weak to good green to blue flashes.

Several analytical methods were employed including basic gemmological testing, X-ray diffraction, raman scattering, scanning electron microscopy and atomic force microscopy.

Magnification revealed tube-like inclusions that looked like plant materials (Fig. 13), clay mineral in tubes or cavities (Fig. 14), siliceous mineral inclusions (Fig. 15), brownish veins in dark brown opal (Fig. 16), white chalcedony and conspicuous fissures in black opal (Sujatmiko *et al*, 2005).

The refractive index ranges from 1.43 to 1.45 and is quite similar to the volcanic Mexican opal. Specific gravity values extend from 1.96 to 2.04, with darker opal tending to have a higher S.G (Fig. 17). Under long wave ultraviolet excitation, most Javanese opal remains inert, but some shows a faint chalky blue fluorescence. Several specimens seemed to emit a weak orange fluorescence along the edges of the material. Under short wave ultraviolet, the opals tend to be inert to a very faint chalky blue.

Figs. 12a Samples show a range of colours of polished Javanese opal.

Fig. 12b Samples of rough and polished block Javanese opal. Some of the black rough samples show a greenish play of colours.

Fig. 13. Sample J1, Play- of- colour in the background with tube-like inclusions appearing like plant material, (30x).

Fig. 14. Sample J7, Curved tube like inclusions filled with clay minerals, (15x).

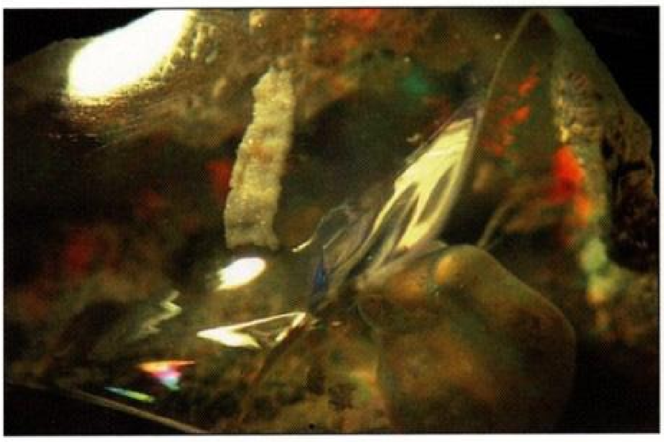


Fig. 15 Sample J2, showing white siliceous inclusions with surrounding play of colour (using reflected lighting at 15x)

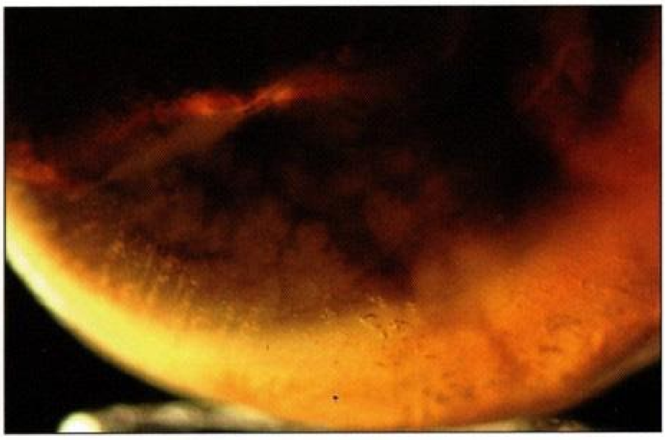


Fig. 16 Sample J15, showing brownish veins in dark brownish opal (transmitted lighting, at 15x).

Fig. 17. Gemmological data of the Javanese opal (Kalimaya)

Gemological test	Result
R.I.	1.43 to 1.45
S.G.	1.96 to 2.04 (darker opals tend to have higher S.G.)
Fluorescence	LW – inert to faint chalky blue with some tinted weak orange at the edge.
	SW – inert to very faint chalky blue
Magnification	Tube-like inclusions (some have a bamboo-like appearance, while others looks like plant material), white chalcedony, smoky brownish veins, conspicuous fissures in black opal.

Fig. 17 Gemological data of the Javanese opal (kalimaya)

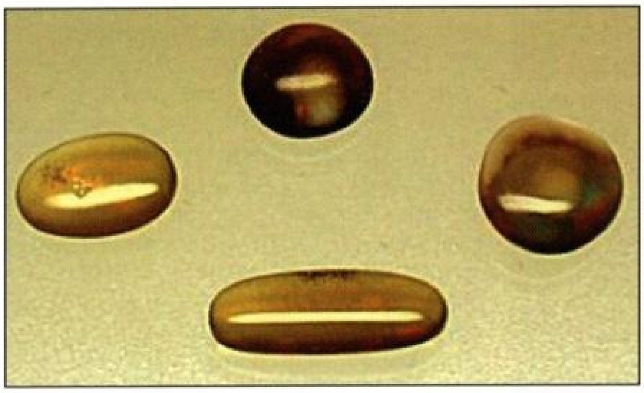


Fig. 18a Hydrophane opal appeared rather weakly coloured, opaque and translucent only along the edge before soaking in water, (transmitted light, 10x)

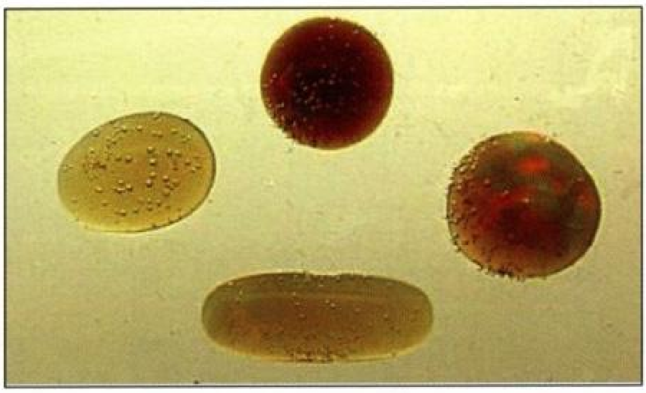


Fig. 18b During soaking in water for two to three minutes, the hydrophane porosity fills and the displaced air appears as minute bubbles, (transmitted light, 10x).

One grayish yellow opal (sample J17) with little play-of-colour appears opaque but once soaked in water for S.G. measurement, the grayish yellow opal became transparent and exhibits slightly more intense play-of-colour than before, (see Webster, 2003) (Fig. 18a & b). This is typical hydrophane opal behavior, and similar material is found in Mexico, e.g. the Magic opal mine in the state of Jalisco. This is slightly different from information provided by John Harris (pers. comm. to E.F., 2007), stating that dark brown Indonesian opals with good play-of-color became much less spectacular after absorbing water amounting from about 10 % to almost half of their mass. This is probably due to the diminution in RI contrast, which increases transparency, but at the same time may lower the opacity which may favour the play of color.

Precious opal from Java

Fig. 18c After soaking in water the hydrophane opal porosity becomes filled and the play of colour becomes more conspicuous, (transmitted light, 10x).

As illustrated by the above material, some of the Javanese opal materials are rather porous. Hence, the locals might coat the opal with polymer to prevent crazing. Gas bubbles could be found around the opal. Occasionally, blue ink from a marker pen is used to paint the back of the opal blue, enhancing the colour appearance (Fig.19).

Six samples of Javanese opal were tested using X-ray diffraction. All opals were indeed CT opals i.e. poorly crystallized α-cristobalite with some

Fig. 19a Blue ink coated on the base of the Javanese opal to imitate blue opal, Fig 19b.

α-tridymite-like stacking. This is a common feature of almost all volcanic opal, such as the Mexican opal tested by Fritsch *et al* (1999) and Enhalf (2007) and also of a Thai opal examined with X-ray diffraction by Ms. Atichat, one of the co-authors. The Thai opal was found in

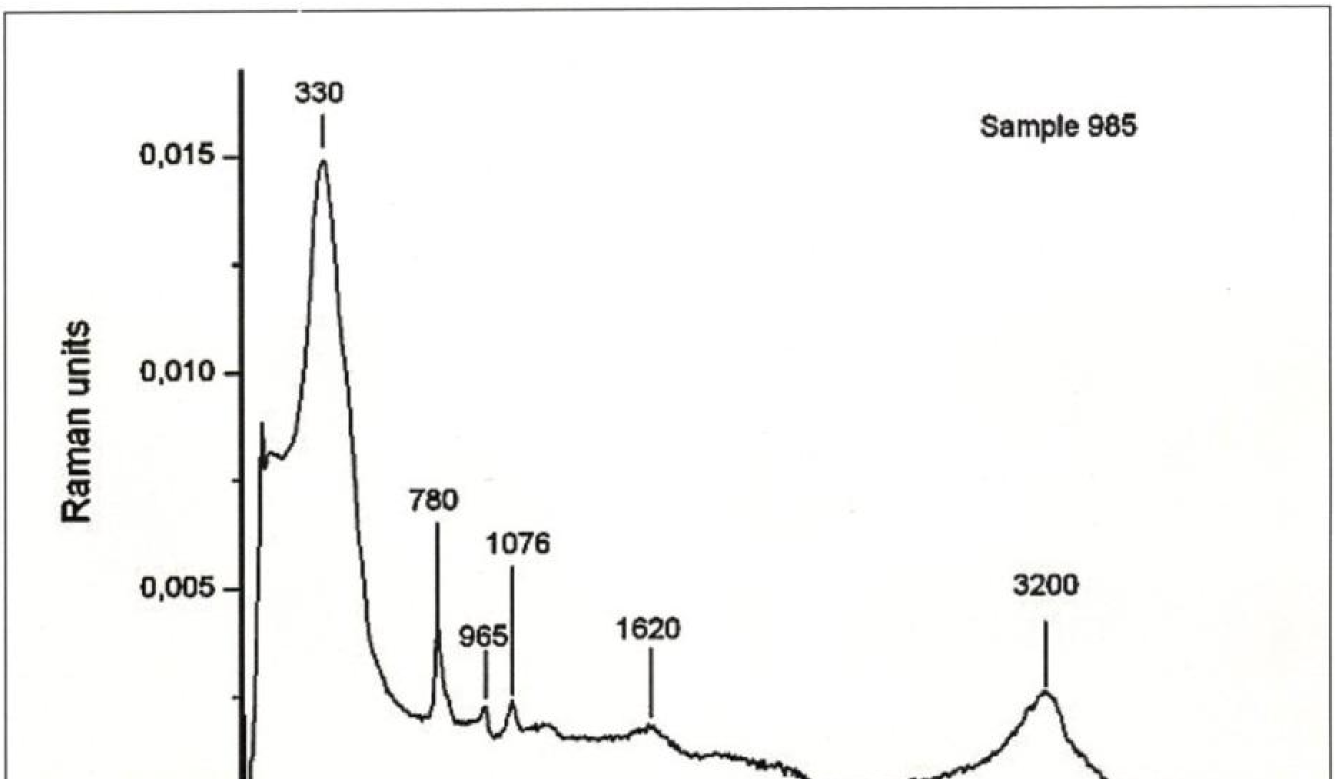


Fig. 20 Raman scattering of Java opals show a main broad band between 306 and 386 cm^{-1}, indicating Java opal is typical a CT opal. The band at 965 cm^{-1} is caused by OH and that at 3200 cm^{-1} by molecular water in the structure. Other bands are silica-related.

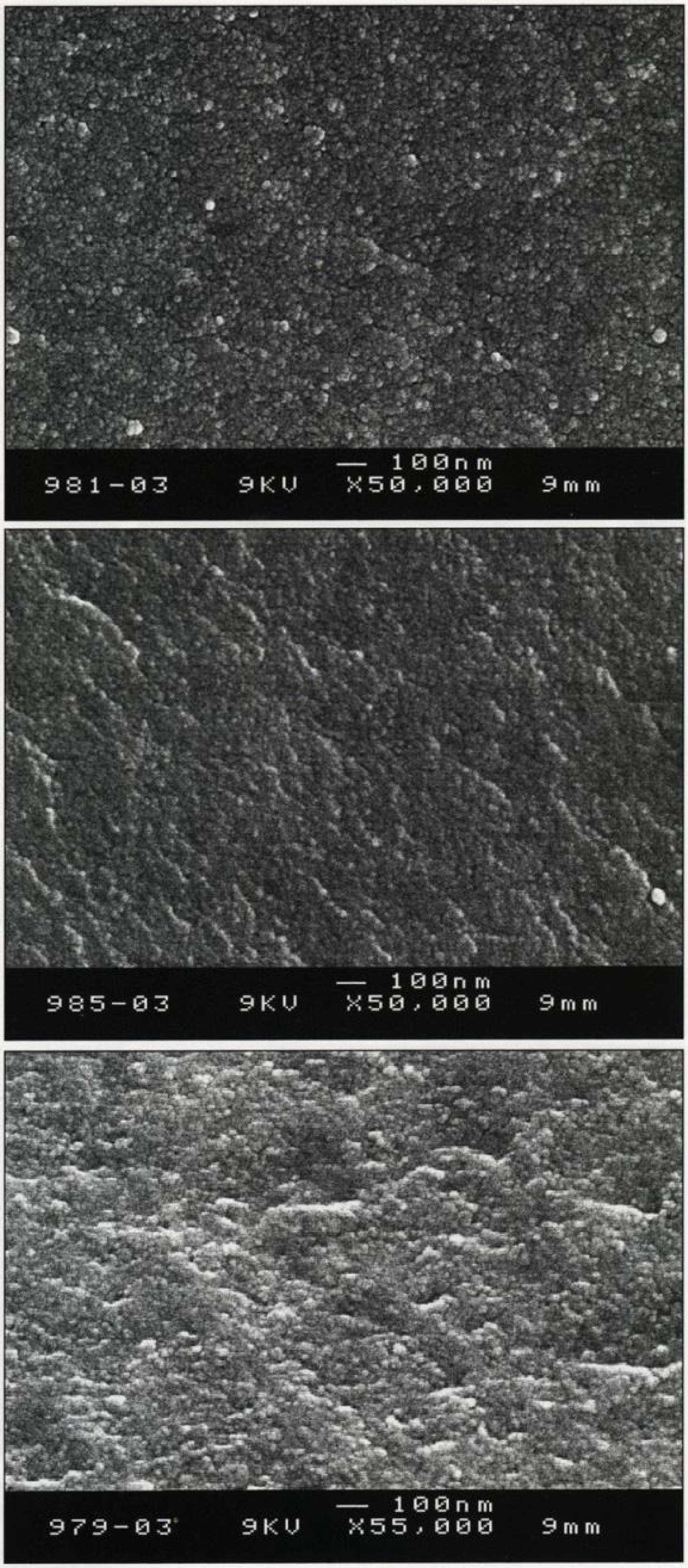
Precious opal from Java

Lamnarai village, Lopburi, Thailand. The CT nature of the Javanese opal was reconfirmed by Raman scattering with data showing the main, broad peak typical for opal, located between 306 and 386 cm^{-1} (Fig. 20) (*opal-A*, such as Australian opal, would peak about 400 cm^{-1}).

A Scanning Electron Microscope (SEM) examination was conducted on several opal samples, sample numbers 979, 981, 985 (Figs. 21a, b and c),

The SEM examination was extended, and samples 979 and 985 were examined with magnifications of 10,000 to 30,000, Figs. 22a and b.

Javanese opal shows the typical texture for a volcanic CT-opal. The basic building block is a nano-sphere of about 25 nm diameter. Sample 979 (Fig. 22) shows a fresh fracture surface with good play-of-color, and an even more spectacular display of play-of-colour is observed in sample 989. However, sample 981 displays a rather disordered stacking structure of the primary spheroids. All samples were etched with aqueous hydrofluoric acid (HF) to develop contrast of the microstructural features. For example, image 98509 (Fig. 22a) then revealed the structure responsible for visible light diffraction. The lepispheres have been dissolved, and within the matrix of nanograins a network of voids was observed, each void being about 200 nm in diameter. The walls around them are made of nanograins, some coalescing to form grains up to 100 nm as in sample 985F09 (Fig. 22a). This is similar to observations on Mexican and Ethiopian play-of-color opal (Fritsch, 1999). Such a structure implies that the lepispheres and nanograin matrix have two different indices of refraction, otherwise light diffraction could not occur. The black play-of-color opal unfortunately started forming cracks after HF treatment, a situation encountered previously on Mexican and particularly Ethiopian opals, possibly due to high water content or residual intrinsic stress. Nevertheless a brief investigation inside the regular scales formed between fractures of the Javanese opal revealed a similar structure as described above.



Figs. 21a, b and c SEM images of Javanese opal Sample Nos. 979, 981 and 985 at about 50,000 magnification.

Precious Opal from Java

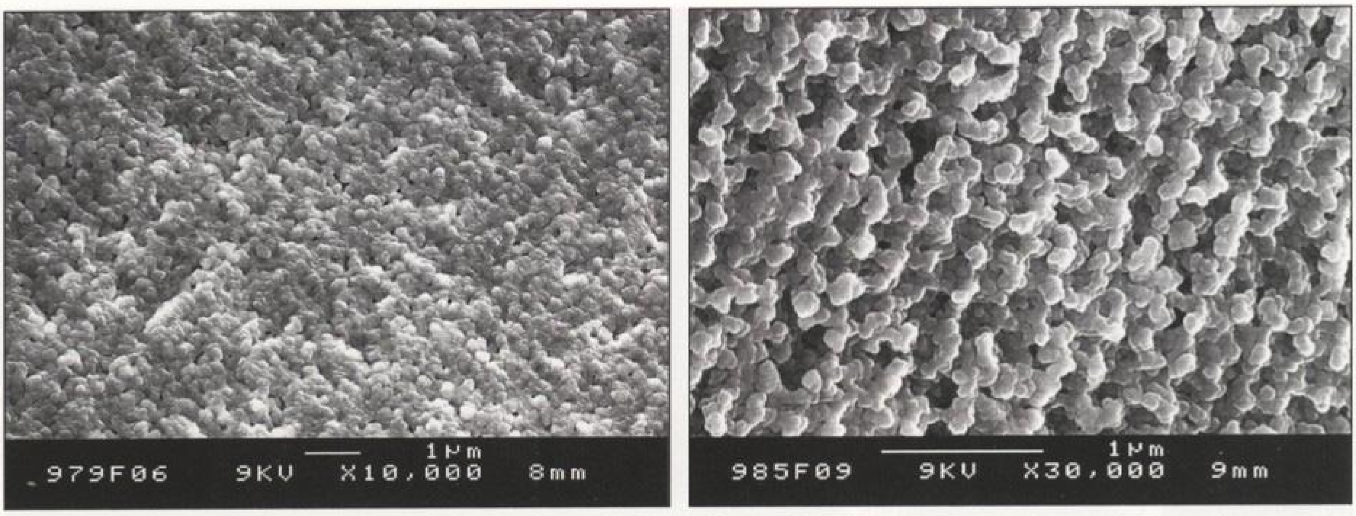


Fig. 22a Sample 979F06, and Fig. 22b, Sample 985F09, the latter showing the nanograin texture row-like pattern resulting in diffraction of light. The nanograin network that diffracts the light has been dissolved, and only the matrix is left (30,000x)

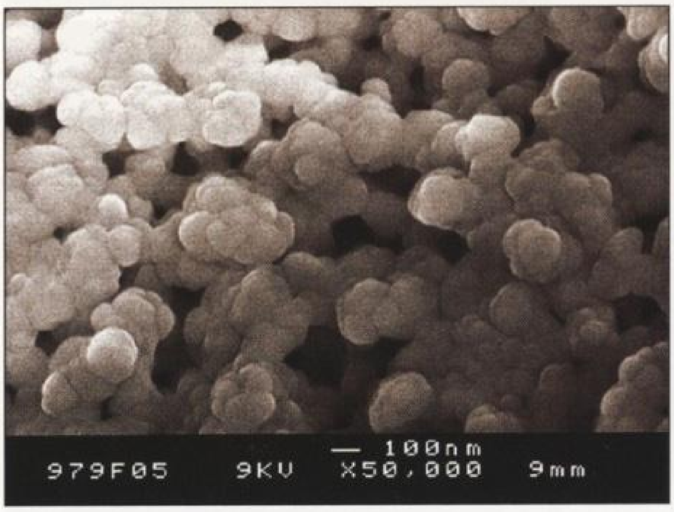


Fig. 23 Sample 979F05 showing the clusters of nanograins forming the walls around the holes left by lepispheres,(50,000x).

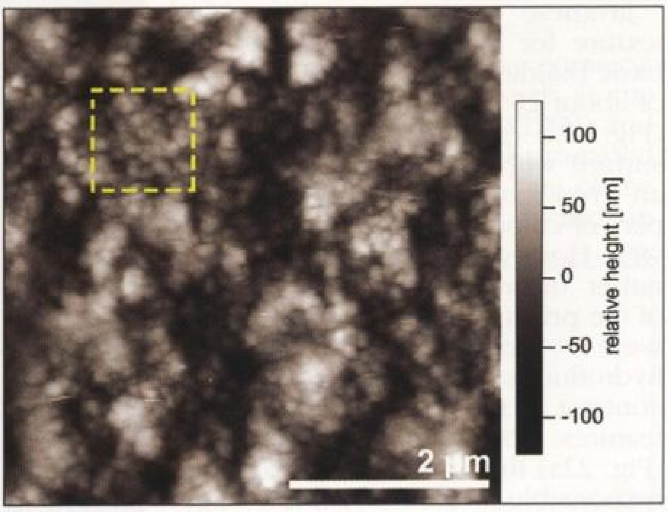


Fig. 24 AFM topography scan of sample 11 (white opal with slight yellowish play-of-colour) shows disordered silica sphere packing.

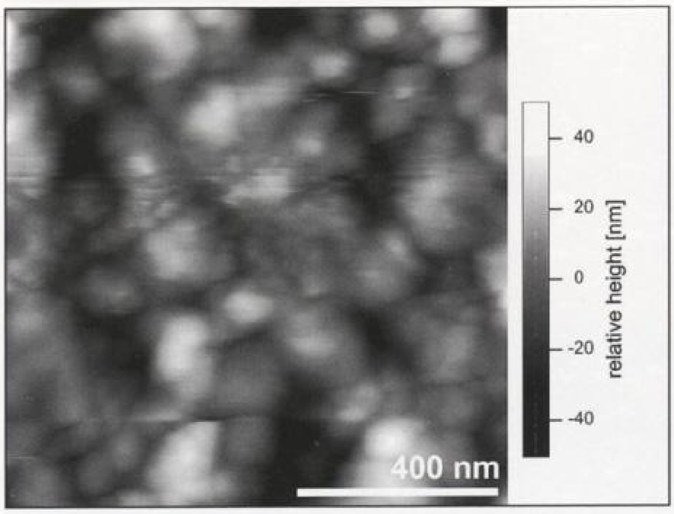


Fig. 25 Detailed scan of region marked in Fig. 24.

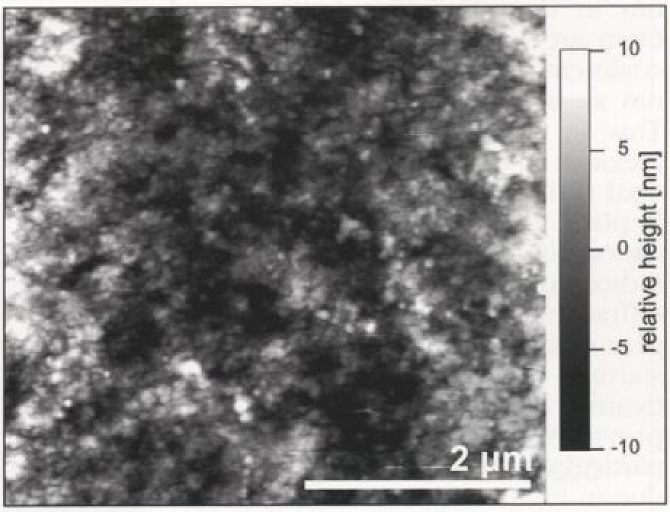


Fig. 26 AFM topography of sample 9, a transparent fire opal with good play of colour, which shows disordered structure but the spheres appear to be relatively uniform in size at about 70nm.

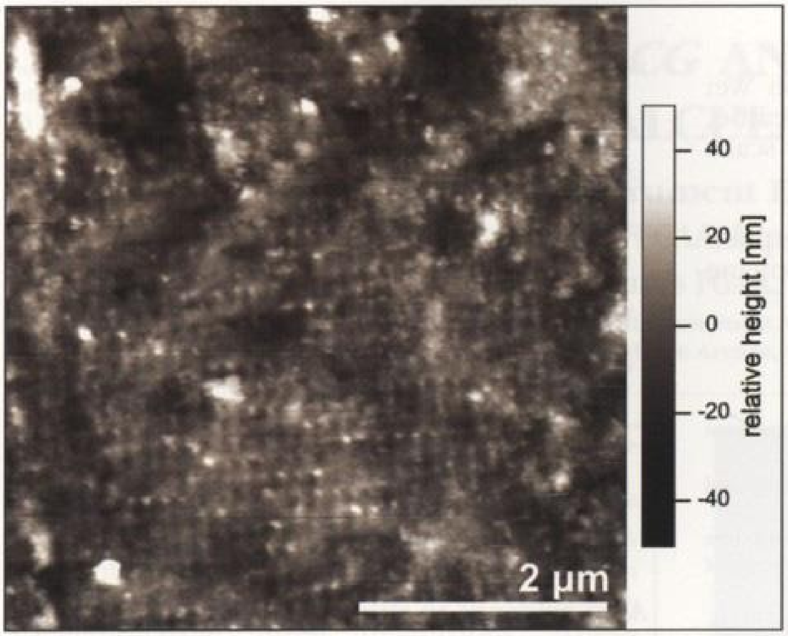


Fig. 27 AFM topography of Sample 8, in a region of intense green play-of-colour. The silica-sphere packing is very regular over a large region and spheroids are spaced approximately 270 nm apart.

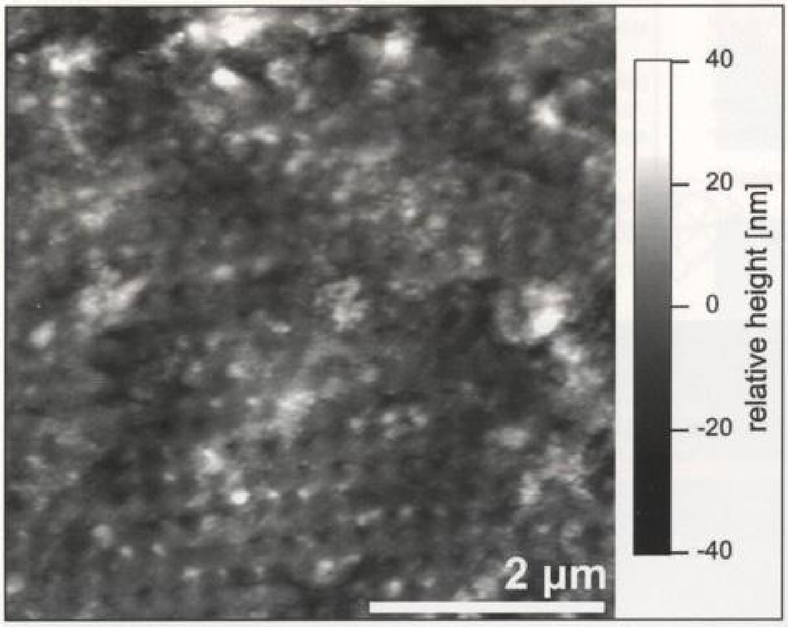


Fig. 28 Detailed AFM topography of a region in Fig 27.

Atomic Force Microscope (AFM) investigations were performed on 6 samples of Javanese opal; three of the results are shown here. The surface consisted of disordered silica spheres (Fig. 24), although sample 11 of white opal showed patches of slight yellowish play-of-colour. A higher resolution scan (Fig. 25) suggests there are silica spheres of two different sizes. Smaller spheres of about 50 nm appear to be wedged between larger 100 nm spheres. * (see Ed's. note)

Sample 9 is a transparent fire opal which displays a good play of colour only with a strong light source. The silica spheres are not well packed but are relatively uniform in size, about 70nm, (Fig. 26).

Sample 8 is a white opal with an intense green play-of-colour. The arrangement of silica spheres within the dotted line is clearly very ordered in comparison to sample 9 and 11, (Fig. 27). A more detailed scan (Fig. 28) shows the spheres to be spaced approximately 270nm apart.

Both SEM and AFM imaging confirm the loose stacking of silica spheres. SEM has the advantage of visualizing more of the surface at once, though AFM can quantitatively determine height variation, as well as correlate visual and topographical characterization.

*(Editor's Note:- Occurrence of dual discrete spheroid sizes in a single diffracting periodic array in Brazilian volcanic opal has previously been also described by Sanders et. Al., e.g. Nature Vol. 275, 21 Sept. 1978, p 201.)

Conclusions

Javanese opal presents all the characteristics of a volcanic opal-CT, comparable with many Mexican and Ethiopian opals. Our data from the SEM and AFM show that silica spheres can be arranged in an orderly as well as a disorderly manner where well-ordered stacking provides the best play-of-colour. Also our data indicate that the Javanese volcanic opal is certainly capable of displaying a very beautiful play-of-color, but it may be significantly different in microstructure to material such as Australian opal or Mexican fire opal.

It could be emphasized that Banten in Indonesia is one of the few sources of true black opal in addition to the classic Australian Lightning Ridge location or minor occurrences elsewhere in Australia, and from Virgin Valley in Nevada.

The blue luminescence of some samples is inherent and possibly related to intrinsic silica defects. These are hypothesized to be tetrahedral silicon with one or two bonds unsatisfied, creating in part a so-called oxygen deficiency center. The lack of intrinsic luminescence of many samples could be explained by the presence of ferric-iron, a known quencher of emission, (Gaillou, 2006). The presence of iron is the inferred cause of the yellow to brown colour, by analogy with Mexican opal. Orange luminescence is known in opal from fossil organic quinones trapped in phyllosilicate inclusions in opaque pink opal (Fritsch et al., 2004). Whether this mechanism operates in Javanese opals remains to be demonstrated.

Precious Opal from Java

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