KLINKER PRECIOUS OPAL DEPOSIT, SOUTH CENTRAL BRITISH COLUMBIA, CANADA - FIELD OBSERVATIONS AND POTENTIAL DEPOSIT-SCALE CONTROLS

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INTRODUCTION

This paper describes the geology and mineralogy of the Klinker opal deposit in south-central British Columbia. The deposit is located within the Tertiary basin that extends 150 km from Okanagan Lake northwest to Kamloops. The area was mapped by Jones (1959) and substantial contributions to the general knowledge of these rocks were made by Church (1979, 1980, 1982), Ewing (1981), Evans (1983), Read (1996a) and Okulitch (1979). It produces both natural precious and common opals. Opal is widespread within the Tertiary basins of British Columbia (Leaming, 1973) and the Klinker deposit is within such a basin. It is located approximately 30 kilometres northwest of Vernon (Figure 1). In 1995 and 1996, the deposit was bulk-sampled using mechanized equipment. Klinker is the first precious opal deposit under development in Canada. Although it is hosted by a volcanic sequence, it may have some similarities with sediment-hosted deposits because of a possible association with an unconformity and intense weathering. Opal extracted from the Klinker deposit typically does not have a tendency to crack or craze when exposed to the atmosphere and is referred to as "stable". It has excellent brightness and multicolour "flash" to "broad flash" patterns. It may be water-clear, orange, honey, red-brown, orange or white in colour. Clarity of the stones varies from transparent through translucent to opaque. At present, doublets, triplets, solid and boulder opal are produced from the bulk sample extracted from the Klinker deposit and are being test-marketed within the Vernon area of British Columbia.

Figure 1. Location of the Klinker precious opal deposit, British Columbia.

Opal is an amorphous form of silica ($SiO_2 \cdot nH_2O$) containing typically 3 to 10 percent water, although some opals contain as much as 20 percent water. X-ray analyses of many opals give weak patterns of cristobalite or tridymite. Common opal may occur mixed or alternate with agate, forming stripes or bands. Precious opal is defined as opal with a "play of colour", caused by diffraction of white light by regular packing of silica microspheres within the mineral structure (Darragh *et al.*, 1976). Common opal has a less ordered packing of silica microspheres within the mineral structure and has no "play of colour". The term "common opal" groups all opals without play of color. The term "fire opal" describes a common opal having a transparent orange to red-orange base color (Downing, 1992). Therefore, precious opal is not a synonym for "fire opal".

Worldwide, precious opal is rare in comparison to common opal. There is a relatively good market for precious opal. Australia produces approximately $CDN 44 million worth of precious opal and the prices of most commercial opal exceed $CDN 40 per gram of rough material. The best grades are valued at more than $CDN 1400 per gram. Good to excellent quality, stable common opal, used as faceting material, such as the orange, transparent variety (also called "fire opal"), ranges in value from $CDN 5 to 300 per gram depending on color. The cherry-red variety is the most expensive. The market for facet-grade opal is smaller than that of precious opal.

Deposits that contain precious opal can be divided into two major categories based on host lithologies: sediment-hosted and volcanic-hosted. Australian deposits of the Coober Pedy, Andamooka and Mintabie areas are excellent examples of sediment-hosted deposits. Deposits such as Spencer (Idaho, USA), Tevera (New South Wales, Australia), La Carbonera and Iris mines (Mexico) and the deposits in the Gracios à Dios area (Honduras) are excellent examples of the volcanic-hosted category. The source of silica for sedimentary-hosted deposits is

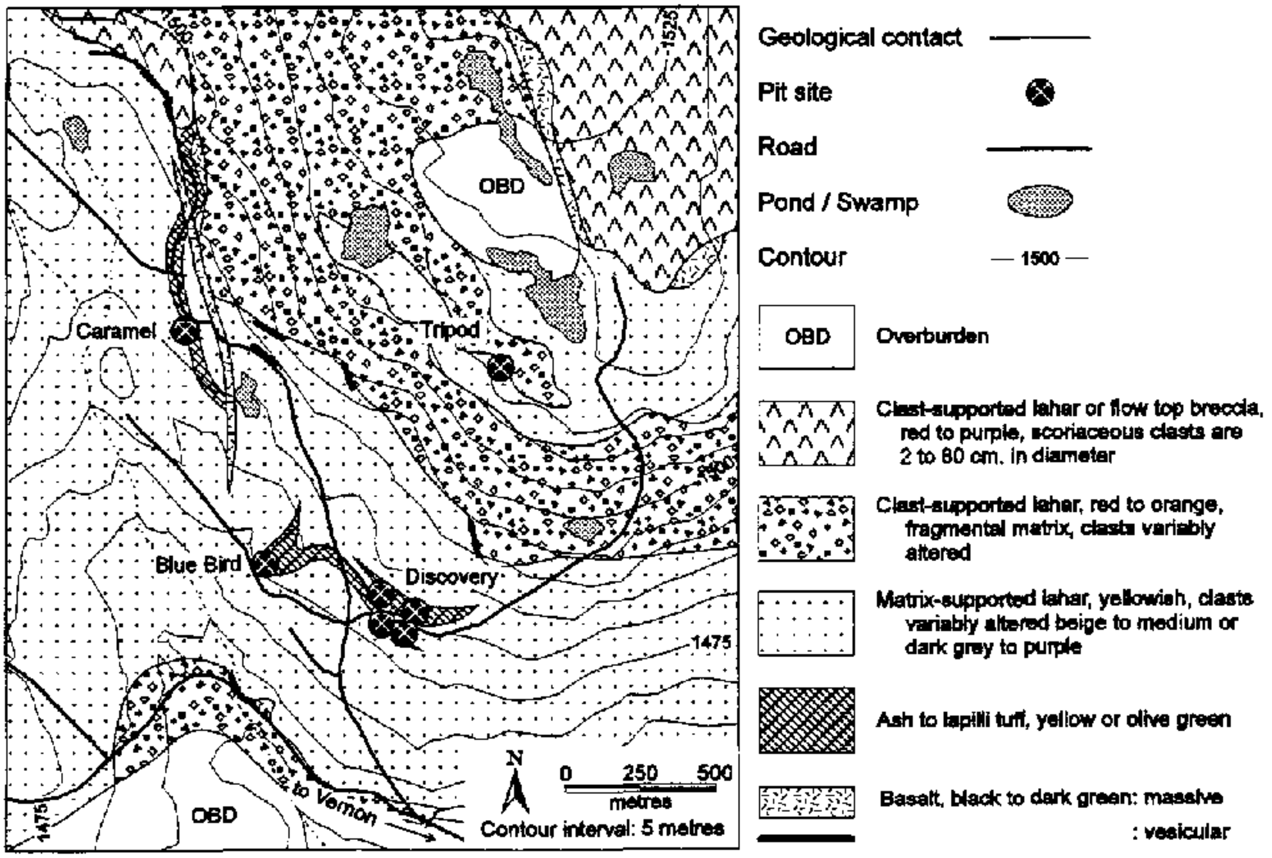

Figure 2. Geology of the Klinker deposit area.

linked to deep and intense weathering while, in general, volcanic-hosted deposits are believed to be genetically associated with hydrothermal activity.

GEOLOGY OF THE KLINKER DEPOSIT

The opal occurrences at the Klinker property are well exposed in an area of clear-cut logging. Most of the exposed rock, with the exception of mafic dikes and the massive portions of lava flows, is strongly hydrothermally altered or weathered. The depth of alteration or weathering is expected to vary substantially, but may be several metres deep as indicated by the presence of fresh rock exposed in the Discovery level 1477 open cut. The Klinker deposit is hosted by clast and matrix-supported lahars and ash to lapilli tuff units of the Eocene Kamloops Group that were initially assigned to the Dewdrop Flats Formation (Read, 1996a) but later interpreted as the Tranquille Formation (Read, 1996b). In the type localities, near Kamloops, the Dewdrop Flats Formation comprises a section of more than 1000 metres thick with nine members. The dominant lithologies are palagonitic basalt and andesite lava flows, flow top breccias, mudflows and dacitic ash flows, aphiric basalt, andesite and dacite flows and tephras (Ewing, 1981a; 1981b and 1982). Radiometric dates reported from Dewdrop Formation vary from 48.6 to 50.5 million years (Ewing, 1981b; Church and Evans, 1983). Typically, the Tranquille Formation underlies the Dewdrop Flats Formation. It comprises andesitic and basaltic tuffs, tuffaceous sediments, palagonite breccia, mudflows, lithic wackes and grey-black shale (Ewing, 1981a and 1982).

Samples of bedded, unconsolidated sediments found in topographic lows overlying the opal-bearing lahars at the Klinker deposit contain Middle Miocene palynomorph assemblages (conifer pollen, angiosperm pollen, fungal spores and cysts) that are similar to assemblages in the Fraser Bend Formation, near Quesnel (Rouse and Mathews, 1979). The samples are assigned to the Barstovian mammalian stage of the Western North American Tertiary, *circa* 13-17 Ma. These palynomorphs, derived from surrounding shore-line habitats, indicate shallow stream or lake edge sediments. Another sample of partly consolidated, bedded tuffaceous sediments containing broad leaf fossils, collected a few kilometres away contains palynomorphs of the same age. A sample of lithified yellow to olive green, ash to lapilli tuff (Figure 2) within the opal-bearing lahars yielded small quantities of conifer palynomorphs that are probably of similar age.

If the Middle Miocene age of the tuff containing opal is confirmed, then the precious opal-hosting rocks are substantially younger than previously thought. On the other hand, if the opal-bearing tuff and lahars belong to the Dew Drop Flats Formation, as suggested by Read (1996a), then an important unconformity could be expected between the opal-bearing sequence and overlying, partly consolidated tuffaceous sediments of mid-Miocene age.

Opal Occurrences

Rock types can be divided into five major lithologies, including matrix and clast-supported lahars, scoriaceous lahar or flow top breccia, ash to lapilli tuff and lava flows or dikes and sills. The lahar units may be relatively thin and possibly repeated, by block sliding, as they dip shallowly (0 to 20°) and closely follow topography (Figure 2). Due to the undulating surfaces of the successive lahars, the strike directions are highly variable over short distances. No drilling has been done on the property and so it is not yet possible to establish the total thickness of overlapping lahar flows and depth to underlying massive and brecciated, unmineralized volcanic rocks that outcrop 500 metres east of the mapped area. Also, it is unknown to which depth precious opal can be found.

Lahars and debris flows are the most abundant of the five major rock types exposed at the Klinker deposit. In general, the lahars are inhomogenous, poorly sorted, unstratified and are nearly tabular on the large scale but have irregular contacts at the outcrop scale. In some lahar layers, the clasts are well sorted. Some flows have as little as 5 percent interstitial material.

Fine-grained, yellow or olive green, ash to lapilli tuff is typically 20 centimetres to 3 metres thick. It is characterized by centimetre-scale bedding, some cross bedding, reverse and normal grading and may form a series of lenses rather than a continuous layer. It appears that this rock forms a single marker unit, however it is possible, due to limited exposure down section, that there may be more than one layer. Near surface, this rock is characterized by loose, yellow, sandy debris and where fresh surfaces are available the rock is olive green. Locally, the bottom contact of this unit is highly irregular. Individual clasts are less than four millimetres in size and typically less than 0.5 to 2 millimetres in size. Precious opal is commonly found within this unit and in matrix-supported lahar immediately above or below it.

Matrix-supported lahar is characterised by a yellow matrix which makes up 10 to 25 percent of the rock. The composition of the sandy matrix is identical to that of the ash to lapilli tuff. Clasts are subrounded to subangular, 2 centimetres to 1 metre in diameter and typically 5 to 10 centimetres across. Clasts consist mainly of massive or vesicular basalt and scoria in various proportions. The colour of the clasts varies from beige to medium or dark grey to purple.

Clast or coarse matrix-supported lahar is more altered or weathered than the previous unit and has a red to orange matrix. The matrix is light red-brown or salmon pink in zones where white zeolite is abundant. Typically, the matrix forms less than 10 percent of the rock. In some instances, small clasts (<3 cm) form the matrix between coarse fragments that are 5 centimetres to 1 metre in diameter. In some areas, chabazite and other zeolites (probably heulandite and stilbite), completely fill vesicles and fractures and locally, zeolites are a major component of the matrix. This unit only contains agate or common or precious opal where zeolites are absent.

Scoriaceous, strongly oxidized, red to purplish, clast-supported lahar or flow top breccia outcrops in the northeast corner of the study area (Figure 2). Due to the flat, rubbly nature of the outcrops, low relief and similarity of clasts, it is not possible to determine if this unit is a lahar or flow top breccia. Over 80 percent of the clasts are scoriaceous, typically ½ to 3 centimetres in diameter and red in colour. However, pumice fragments may be as much as 60 centimetres in diameter. Twenty to eighty percent of the rock is void space and is not known to contain opal or the zeolites chabzite, heulandite or clinoptilolite. However, loose pieces of agate were found on several outcrops.

Basalt is dark green to black on fresh surfaces and medium green or beige-brown on altered surfaces. It is mostly massive but, in some places, moderately vesicular and more altered near the tops of flows or sills. Mafic phenocrysts are typically less than 3 millimetres in size and form less then 8 percent of the rock. Outcrops of the massive variety are characterized by flat polished surfaces, except where it coincides with breaks in slope and then is blocky to angular. Because of the flat nature of basalt outcrops, it is often difficult to determine if it forms sills, dikes or flows. This unit normally does not contain any opal. However, in one outcrop near the Caramel pit, a mafic dike contains rare opal fracture fillings. This shows that some dikes post-date lahar flows and predate opal mineralization. In some areas, stretched vesicles are filled by radiating zeolite crystals that may be thompsonite.

Cross Sections

Sections of the Caramel and Blue Bird pits are illustrated on Figures 3 and 4 respectively and located on Figure 2. They show the detailed geology in the pits and illustrate the subhorizontal to shallow dipping aspect of the lahar units. They also illustrate the relationship between individual lahar flows and the enclosed ash to lapilli tuff. In the Caramel pit, the oldest unit appears to be coarse, matrix supported, opal-bearing lahar, with a very irregular upper contact. This is overlain by centimetre-scale, bedded tuff, which is, in turn, overlain by another coarse, matrix-supported, opal-bearing lahar. Above that is a dark green to black lava flow, massive near its base and very vesicular near its top. The vesicles are elongate and filled with common opal or agate. This flow is overlain by a yellow, matrix supported lahar. In the Bluebird pit, reworked ash to lapilli tuff is discontinuous and appears to have been eroded by the overlying lahar flow. The mud seams in the pit face (Figure 4) consist of very fine-grained layers of soft material, probably a mix of clay and feldspar, ½ to 5 centimetres thick. In the Bluebird and Caramel pits, opal is found immediately above, below and within the ash to lapilli tuff. It is important to note that the ash to lapilli tuff occurs in all precious opal bearing pits.

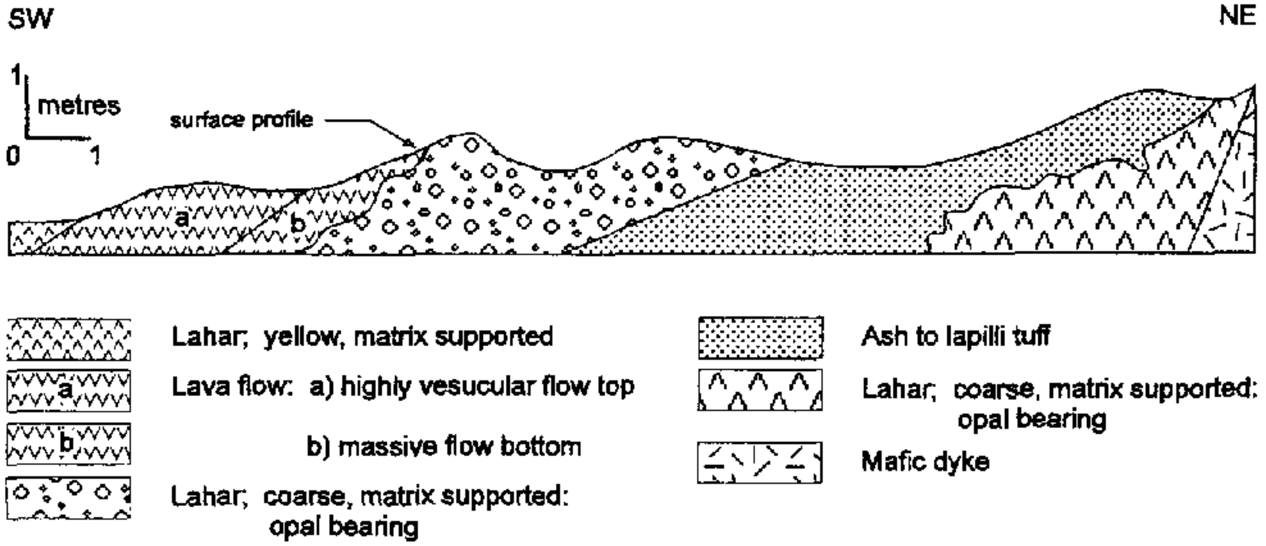

Figure 3. Cross section of the Caramel Pit, looking northwest. For location see Figure 2.

MINERALIZATION

Precious opal occurs as open space fillings, mainly within fractures, voids and vesicles. Other fracture fill minerals at the Klinker deposit are agate, non-precious facet-grade opal, common opal, quartz, celadonite, amorphous manganese oxides, clinoptilolite, heulandite, stilbite, clays and rarely, calcite. Non-precious, facet-grade opal is typically orange and honey coloured, similar to Mexican "fire opal". Common opals occur as transparent, translucent and opaque types in white, honey, brown, amber, orange and grey colours. Quartz can occur as small, inward facing, terminated crystals within vugs. X-ray diffraction analysis reported by Awram (1996) notes that kutnahorite and saponite co-exist with opal. Opal from the Klinker property is classified as opal-CT, using Jones and Segnit's (1971) grade classification (Awram, 1996). Most stones from deposits with precious and common opal are classified as opal-A (Frye, 1981). Detailed studies of opal microstructure are underway to confirm and refine Awram's findings.

CONTROLS ON OPAL DISTRIBUTION

Mineralogical Zoning

The first and most readily apparent control on opal distribution is stratigraphy and rock porosity. As previously mentioned, opal occurs within ash to lapilli tuff and immediately adjacent matrix-supported lahar. However, at the scale of the property there are also mineralogical controls. Opal and agate have a complex relationship with zeolites. They do not exist in zeolite-rich zones that contain chabazite, the most abundant, heulandide, clinoptilolite and stilbite. These are the most significant vesicle and fracture fillings and matrix

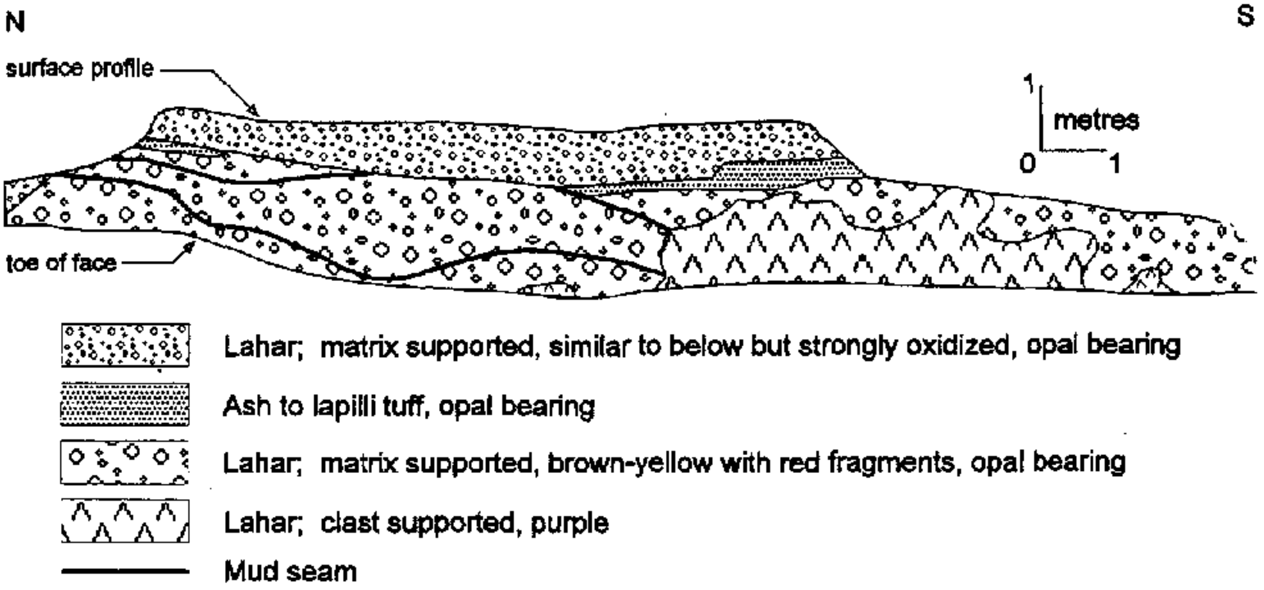

Figure 4. Cross section of the Blue Bird Pit, looking southeast. For location see Figure 2.

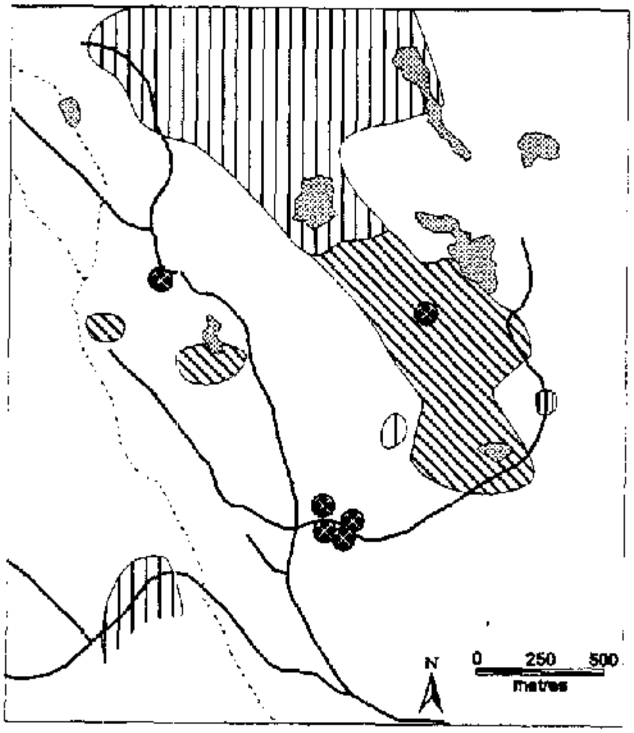

Figure 5. White zeolite-bearing zone (vertical lines) and yellow-sugar coating zone (angle lines); Klinker area.

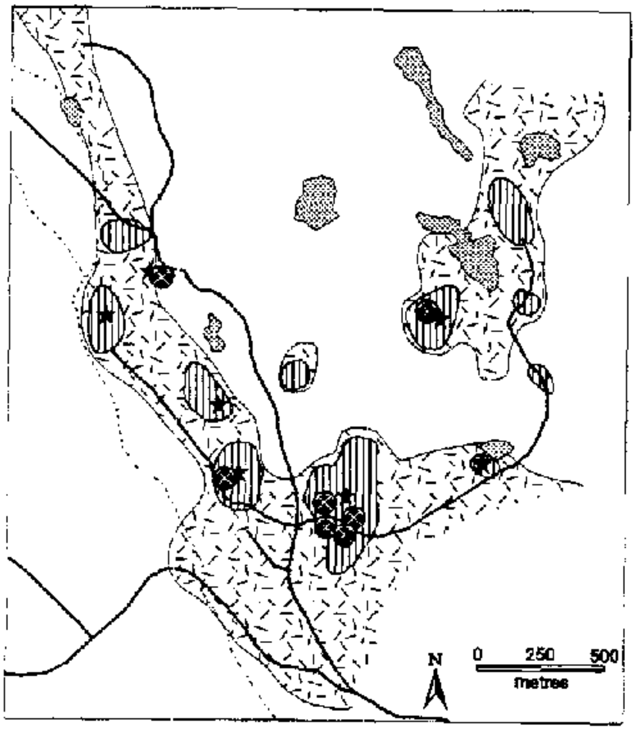

Figure 6. Distribution of agate (random lines), common opal (vertical lines) and non-precious facet-grade opal and precious opal (stars); Klinker deposit area.

cement in the north central part of the map area (Figure 5). Opal and agate occur where the zeolite-rich fillings give way to a yellow, sugary coating in fractures and vesicles, towards the southeast (Figure 5). X-ray diffraction patterns of this yellow coating yield weak peaks for tridymite with minor clinoptilolite(?). This coincides broadly with the change of red, strongly oxidized coarse matrix-supported lahar to yellow, fine-grained matrix-supported lahar. The yellow, sugary coating coexists with agate and possibly opal in the east central part of the map area. The only exception to the mutually exclusive relationship of white zeolites and silica is in the Caramel extension zone. There the subhorizontal, undulating contact between two distinct lahar flows parallels the current erosional surface. It may be that one flow contains agate, common and precious opal, while the other flow contains white zeolite-filled vesicles.

Another major mineralogical control is that opal occurs only within broad areas of agate mineralization and precious opal only in small areas within common opal mineralization (Figure 6). Agate has the widest distribution, forming a northwest trending belt. White, opaque common opal, brown or honey opal, transparent opal and precious opal occupy successively smaller, more restricted areas. Precious opal is known to occur at only a few locations (Figure 6). A similar range in mineralogy exists in individual fractures. Some are filled only by agate, by agate and common opal, by common opal and transparent common opal and finally by non precious orange, honey or yellow facet-grade transparent opal and precious opal. In general, agate and precious opal do not coexist in a given fracture without the presence of one or both of common opal and common transparent facet-grade opal.

Structural Controls

Most of the precious opal on the property occurs as vesicle and fracture fillings. Consequently, the distribution and orientation of fractures is important. The orientation of the fractures is summarized on comparative stereographic plots (Figure 7). Most data comes from the Discovery, Blue Bird, Caramel and Caramel Extension pits because intense weathering makes acquisition of structural data elsewhere difficult. Figure 7a indicates most of the fractures in the Klinker area are steeply dipping to subvertical and strike 170°, regardless of fracture fillings. Figure 7b indicates that the same pattern holds for fractures filled by silica minerals, agate, common and precious opals; there are two other less pronounced orientations at 073° and 035°. Figure 7c shows similar orientations for precious and transparent common opal filled fractures with another subset at 060°, based on very limited data. In summary, there is no obvious statistical correlation between fracture orientations and mineral fillings. The main fracture set is roughly 170°, but minor subsets may be important. The 170° preferred orientation coincides the major lineaments that may have acted as solution channels and extend beyond the property boundaries. These lineaments were detected by air-photo interpretation by R. Yorke-Hardy and confirmed by Penner and Mollard (1996). Both the mineralogical and structural findings can be used as exploration guides on the property, but it is not known if it can be applied beyond there.

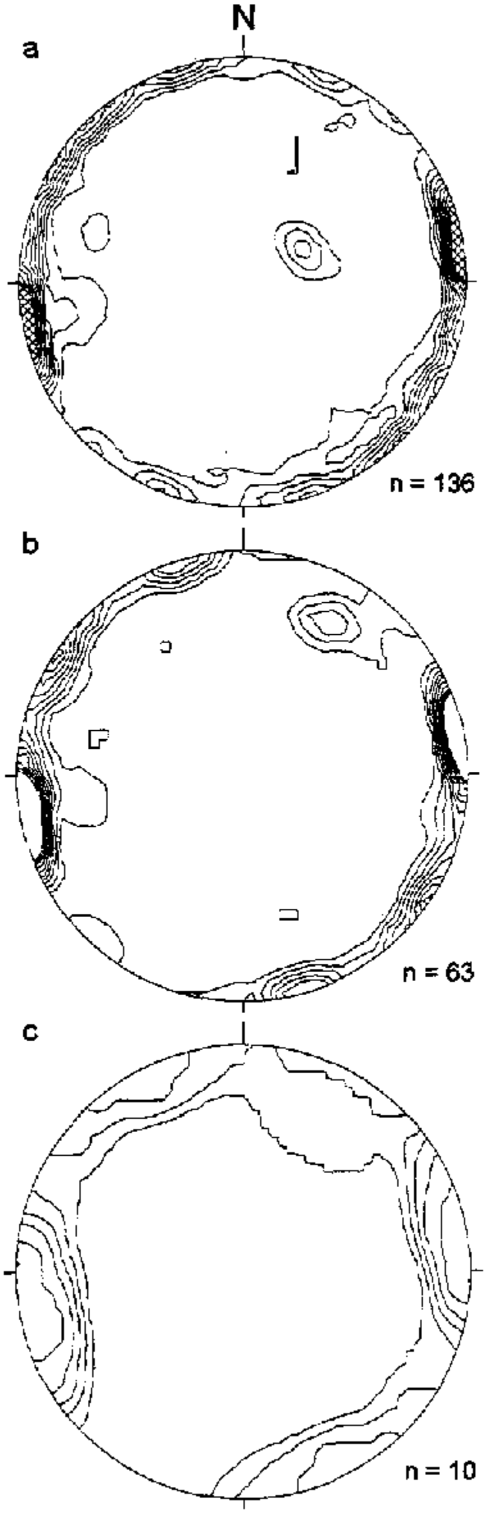

Figure 7. Preferred orientations of poles to fracture planes sorted by fracture fillings: a) all fractures; b) fractures with silica filling only; c) fractures filled by facet-grade and precious opal. Lower hemisphere plot. n = number of poles. Contours are 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 times unity. Cross-hatching in areas greater than 10 times unity. Comparative plots made using the method of Starkey (1970, 1977, 1993).

SUMMARY

The most significant findings of our fieldwork are the mineralogical guides to the potential distribution of precious opal at the property. Precious opal mineralization occurs within ash to lapilli tuff and adjacent lahar units and is surrounded by larger zones that contain agate and common opal. Opal mineralization does not occur within lahar that contains white zeolite fracture and vesicle fillings or matrix cement. There is no preferred strucutral control to opal mineralization. Rock types are divided into five major lithologies, including matrix and clast-supported lahars, scoriaceous lahar or flow top breccia, ash to lapilli tuff and lava flows or dikes and sills. We have established that ash to lapilli tuff overlying the opal-bearing lahar sequence is of mid-Miocene age and is substantially younger than previously believed. Opal-bearing lahars are probably of the same age, but if they belong to the Dewdrop Flats Formation, as postulated by Read (1996a), one would expect a major unconformity between the opal-bearing sediments and overlying mid-Miocene, partly consolidated tuffaceous sediments.

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