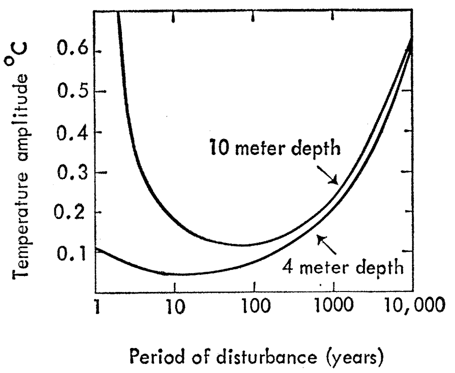

Fig. 4. Amplitude of a harmonic-temperature disturbance that will cause a 10-percent error in the measured temperature gradient in typical lake-bottom sediments. Curves are for measurements of depths of 4 and 10 m.

thermal gradient, but these periods can at least be recognized by the measurable nonlinearity of the gradient. The very long periods are less effective but, because of their long wavelength in the sediment, the effects will appear linear over distances of 5 to 10 m.

There is abundant evidence from climatic records of variation of 1° to 2°C in atmospheric temperature over periods of tens and hundreds of years. These variations are highly attenuated in the bottom water of temperate lakes by the relative stability of water at its 4°C maximum density point (*6*). This large attenuation factor (30 times or more) suggests that long-term climatic effects may not seriously affect the measurement of terrestrial heat flow in lakes.

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6 August 1965

Chert: Modern Inorganic Deposition in a Carbonate-Precipitating Locality

Abstract. *Chert is precipitating as gelatinous opal-cristobalite in lakes associated with the Coorong Lagoon of South Australia. Dolomite, magnesite, and magnesian calcite are also being deposited. High* pH *(9.5 to 10.2) causes dissolution of detrital silicates; lowering of* pH *(7.0 to 6.5) and drying of the lakes cause precipitation of chert.*

Chert is inorganically precipitating in ephemeral lakes associated with the Coorong Lagoon (*1*) of South Australia. The term *chert* generally applies to a variety of fine-grained silica that precipitates initially as an almost-amorphous gel composed of water and small crystallites of rudimentary cristobalite structure; this material gradually recrystallizes to chalcedony, a variety of microcrystalline low quartz that is the major constituent of ancient chert (*2*).

In many places, such as the Gulf of California and the zones of high productivity in the oceans, sediments are receiving large contributions of biologically precipitated opaline silica. We now report the first discovery, to our knowledge, of inorganic precipitation of silica gel in a modern sedimentary environment.

The dominant precipitates of the lakes are dolomite, magnesite, and magnesian calcite. The surface of the sediment, which completely dries during the dry summer, contains plates of desiccated sediment that are related to mud cracks. These plates are more resistant to softening when wet than is common for normal dried carbonate sediments of the area. Material in the outermost several millimeters of these plates has a porcelaneous texture. This somewhat hardened surface extends around the sides and edges of the plates but it is not apparent on the undersides. The plates, typically about 1 cm thick and about 10 cm across, are complex; some of them contain fragments indicating that the plates have been broken and reincorporated. The edges are rounded and the upper surface is pitted and irregular. In some places on the lake bed, where they remain in their original position with respect to desiccation cracks, the plates cover almost the entire surface of the nonindurated sediment and constitute a bed which extends for tens to hundreds of meters. Some of the plates are distorted.

The carbonate minerals from the plate material were dissolved with 1:1 hydrochloric acid, leaving a gelatinous substance. If the fragments were dissolved very slowly in cold hydrochloric acid, the remaining gelatinous material retained the original shapes of the fragments. Most of the sediment at the surface of the lakes becomes quite hard to a depth of 20 cm or more during seasonal drying, but softens again when saturated with water. This unconsolidated sediment contains a noncoherent insoluble gel.

X-ray diffraction patterns of the gel (Fig. 1) are very diffuse and show an extremely broad diffraction maximum centering at about 4.0 Å, which is characteristic of opal-cristobalite (*2*). Superimposed on this broad and diffuse pattern is a pattern of detrital quartz. Heating the opal-cristobalite to 940°C for 10 hours produces material that yields a sharp cristobalite reflection at about 4.04 Å (*3*). X-ray diffraction patterns of the unconsolidated gel and of the gel that tends to retain

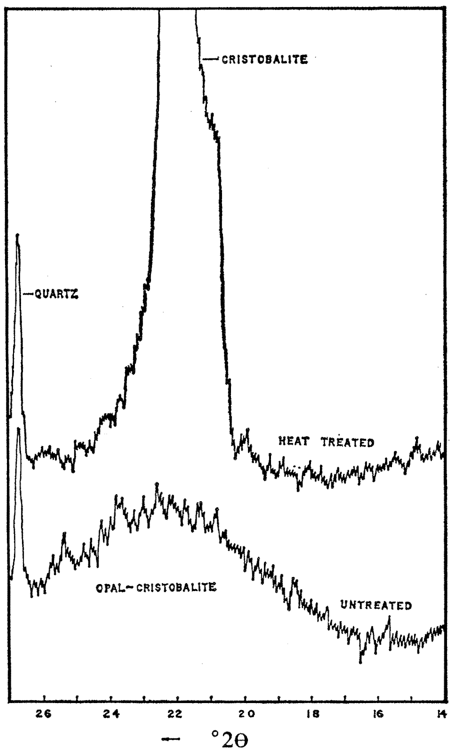

Fig. 1. X-ray-diffractometer traces of opal-cristobalite from dolomite-magnesite sediment: normal material (bottom), and similar material heated at 940°C for 10 hours (top).

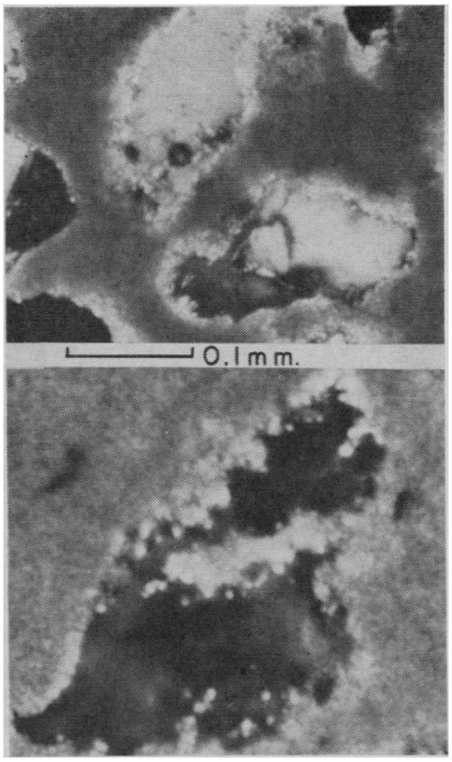

Fig. 2. Quartz grains, photographed in thin section, with crossed polarized light, showing pitting and destruction of grain boundaries from dissolution. The halo is of fine-grained carbonate and opal-cristobalite.

the shape of the fragment from which it derived are virtually identical. Electron photomicrographs show basic globular units about 0.1 to 1.2 μ in diameter, containing subunits about 200 Å in diameter.

The opal-cristobalite ranges from 1 to 6 percent by weight in most of the sediment and is considerably higher in local segregations and case hardenings, ranging to 100 percent where it fills voids. Most of the opal is in the unconsolidated mud since this is much more abundant than the consolidated plates.

Sand-sized detrital grains, consisting mostly of quartz and a little feldspar, have a peculiar surface texture, being completely covered with small pits. Many are also deeply corroded and have complex and irregular shapes that are not explained by abrasive processes. In thin section (Fig. 2) they commonly have ragged fringes, and a halo of fine-grained silica and carbonate surrounds them. The halos appear in places to be related to the original shape of the detrital grains. The grains undoubtedly have been the source of much of the silica that is now found as the gelatinous hydrated precipitate. Clay minerals are obscured by this dominant gelatinous material in the fine fraction; however, it is likely that some detrital clays have served as a source of silica and that some new clays are forming authigenically. Some biogenic opal may have been introduced to the sediment and subsequently dissolved; playa lakes commonly abound in siliceous organisms. Some diatoms are found in the open Coorong Lagoon itself; but they have not been found in the ephemeral lakes associated with the Coorong or in their sediments. Dissolved silica is certainly also carried into the lakes by water draining from the surrounding, largely calcareous, dunes, which contain detrital quartz and possibly some biogenic opal.

The sediments in these lakes are modern. Carbon-14 ages of only hundreds of years have been obtained on unconsolidated dolomite (*4*); less than 1000 years on semiconsolidated magnesite. The opal-cristobalite impregnates the carbonate mud and so it must also be modern.

The gross chemical conditions within these lakes are suited to the formation of silica precipitates from silica contained in detrital quartz and other silicate minerals. The *p*H of lake water commonly rises to 10.2 during active photosynthesis by *Ruppia maritima* Linn.; the brine, just as it approaches maximum concentration and either dries or sinks into the mud, has *p*H of about 8.2. Beneath the surface of the sediment there is a zone of rotting vegetation in which the *p*H of interstitial solutions is as low as 6.5. It is more or less at the boundary between these two *p*H realms that opaline silica is most obviously precipitating on the surfaces of the hardened plates.

The lake water has a rather wide fluctuation of *p*H that follows a seasonal pattern; daily fluctuations in *p*H are much smaller than seasonal changes. The ionic balance of the dissolved salts during periods of low salinity is similar to that in sea water; salinity ranges from about half that of normal sea water to complete saturation. Precipitation of minerals occurs throughout the drying season, and both changes in dissolved salts and variations in plant activity may be responsible for the seasonal variations in *p*H.

The solubility of amorphous silica is virtually independent of *p*H from 1 to 9, but increases rapidly above *p*H 9 (*5*). Thus fluctuations in *p*H in these lakes vary from conditions in which silica is very soluble (400 to 500 ppm) to conditions in which it is relatively insoluble (120 ppm). Detrital quartz would dissolve in the solutions of high *p*H and reprecipitate during low stages of the lakes because of both reduction in *p*H as the plant life dies and as the brine concentrates and sinks into the sediment, and the final drying of the lake bed. These processes, as they affect quartz, are, to a first approximation, considered independently of the buffering effect of reactions involving aluminosilicates (*6*).

The silica is being transformed mainly from quartz, a phase of low free-

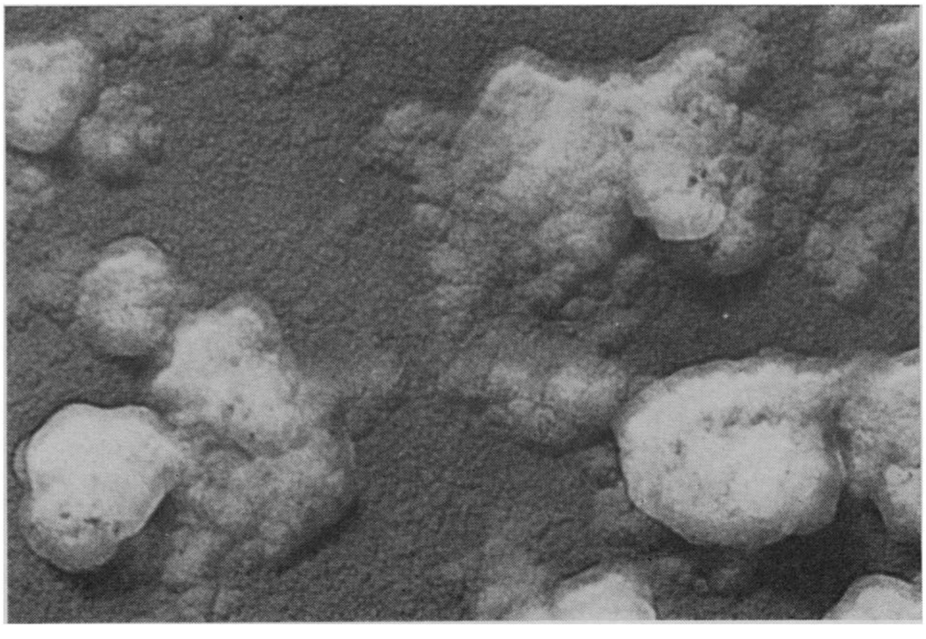

Fig. 3. Inorganic modern chert; electron-micrographic replica (platinum-carbon) of opal-cristobalite from carbonate sediments. [B. E. F. Reimann, × 160,000]

energy and low solubility, to opal-cristobalite, a phase of comparatively high free-energy and solubility. Under these conditions it is unnecessary to postulate the sedimentation of phases of high free-energy, such as biogenic opal or volcanic glass, to provide a source for the silica. The main change in *p*H is seasonal; hence the energy necessary for this transformation is supplied to the chemical system by solar radiation. The dissolution of detrital quartz and other silicates in the lake bed is analogous to weathering.

Aspects of ancient rocks, such as slump structures, breccias, and distortion of bedding by compaction around nodules, indicate that some cherts have been formed at least partially during deposition or prior to final lithification and compaction (*7*). Impregnation of the normal carbonate sediment in these lakes with opaline silica has produced locally a lithification that is rigid and resists softening when wet, and which could serve to buttress the hardened material against compaction. Fragments of this material are being incorporated as an edgewise conglomerate. Thus, this instance of the modern formation of chert clearly shows two of the criteria most commonly cited as geological evidence of contemporaneous formation of chert.

It seems unlikely that this instance of precipitation of silica is unique; its interpretation surely applies to a large number and variety of ancient carbonate rocks. Recent work on the formation of magnesian carbonates (*8, 9*) has shown that high *p*H is commonly associated with precipitation of both dolomite and magnesite. Many features in ancient rocks [for example, the Mississippian carbonates of the Cumberland Plateau (*10*)], such as deeply corroded, detrital, quartz grains, chert-laden dolomite, and the filling of small veins and holes with chert, are duplicated in these modern sediments. It is thus apparent that such features can form very early in the depositional history of this type of sediment.

Walker (*11*) has discussed replacement relations between carbonate and silica minerals from ancient rocks that are very pertinent to this study, mentioning *p*H measurements from the Coorong area in his arguments. Siever (*12*) has stressed the possibility that deposits from sodium carbonate lakes may show appreciable amorphous silica; one such, Deep Springs Lake, has a *p*H of 9.5 to 10.0 and is precipitating dolomite (*8*).

Clearly, detrital quartz and perhaps other silicate minerals can serve as an important source of silica, provided the appropriate chemical conditions are available to dissolve them. Such conditions are provided by environments also suitable for precipitation of the magnesian carbonates. Opal-cristobalite can be formed by direct inorganic precipitation at the time of deposition of the sediment. This opaline silica, just like its biologically formed counterpart, will be reorganized within the sediment in the course of geologic time.

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23 June 1965

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Tritium: Distribution in Busycon canaliculatum (L.) Injected with Labeled Reserpine

Abstract. *Tritiated reserpine was injected into the body cavities of specimens of* Busycon canaliculatum *(Mollusca, Gastropoda). Only the ganglia, liver, and kidney were radioactive throughout the 14-day experiment. Radioactivity of the kidney and liver increased after the first measurement; that of the ganglia declined during the first day but later remained constant.*

Injection of reserpine into mollusks alters their behavior and decreases the 5-hydroxytryptamine (serotonin) content of their ganglia. Neither effect appears immediately, but, once evident, both last for several weeks (*1*).

The effects on behavior are due to chronic alteration of the tonus of the muscles that regulate the posture of the animals. To establish whether this results from direct action of the alkaloid on the muscles or is mediated by the serotonin or other amines released from the nervous system by the drug, one must know whether reserpine is concentrated in the nervous system in preference to other organs. I have therefore investigated the distribution of radioactive label in the bodies of mollusks injected with tritiated reserpine.

Shortly after reserpine is injected into the blood lacunae and before its effects are apparent, concentration of the alkaloid is higher in the mass of the solid organs than in the blood itself; therefore the lag does not depend on a slow rate of diffusion of the injected material. The long duration of the effects is linked to the presence of reserpine or of one of its metabolites in the ganglia of the treated animals, since radioactivity derived from the injected drug can be detected in the ganglia for at least 14 days after the injection.

Doses of 114 μg of tritiated reserpine (*2*) were injected into the body cavities of specimens of the common Atlantic whelk, *Busycon canaliculatum* (L.). The animals were kept in aquariums at constant temperature (24°C), four in each aquarium. The effects of reserpine on posture appeared 6 to 12 hours after the injection, were fully developed within 1 to 2 days, and lasted with the same intensity throughout the 15-day experiment.

The amount of radioactive material

Table 1. Radioactivities (count/min) of known quantities of tritiated reserpine added to samples; standards used in the experiment. Values (with S.E.) are the means of five determinations for sea water and blood; of ten for tissue.

Sea water (1.0 ml)	*Busycon canaliculatum*	
	Blood (1.0 ml)	Tissue* (100 μg)
Background noise		
86.2 ± 1.39	100.8 ± 3.37	156.5 ± 6.55
Total activity of 0.5 μg tritiated reserpine		
751.0 ± 27.25	733.2 ± 23.85	807.0 ± 43.70

* Equally composed of kidney, muscle, and connective tissue.