calculation. Colin Norman (Space Telescope Science Institute) presented a simple analytical model in which the input parameters are the rate of mass and energy addition to the ISM and its clumpiness. It predicts that tightly wound spiral galaxies should have three stable ISM phases and more open ones only two. Other testable predictions include variations of the ISM components with radius and with time during a burst of star formation. The dense-molecular-cloud phase, which is dissipated once significant numbers of stars form, may be regenerated at the tips of expanding merged supernova-remnant bubbles, whose shapes have been distorted by the rotation of the galaxy, according to Jan Palous (Astronomical Institute, Prague).

Star formation, just alluded to, is obviously the single most important process in the life of a galaxy. It is also a very inefficient one, at least in the Milky Way, where typically only a few per cent of the mass in a giant molecular cloud complex has formed stars before the clouds are disrupted. We see no local examples of the kind of efficient star formation that occurs in starburst galaxies, according to Philip Solomon (State Univ. New York, Stony Brook).

Edith Falgarone (California Institute of Technology) pointed out that the known amount of turbulence in molecular clouds is sufficient to stabilize them against collapse and star formation on the free-fall timescale. Consistently, molecular clouds at the Galactic Centre, with larger turbulent velocity dispersions, are even less than averagely efficient star formers despite their high densities (Bally). One wonders, of course, why turbulence is less stabilizing in some other galaxies.

The low efficiency of star formation shows up in the total galactic rate at which gas is being turned into stars massive enough to ionize their surroundings and to give rise to core-collapse supernovae. Heiles, inventorying OB star associations and their adjacent ionized hydrogen gas, finds that a star bigger than 8 solar masses ($M_\odot$) — a likely minimum for type II supernova progenitors — forms only once every 112 years. Solomon, relying on a combination of carbon monoxide and infrared continuum emission, estimates that 0.5–0.6 $M_\odot$ per year goes into stars above 2 $M_\odot$ (ionizers), corresponding to about two core-collapse supernovae per century. The two estimates should be regarded as consistent within their errors. Both are at the low end of generally-advertized rates for the Milky Way.

A second very important aspect of star formation is that it seems to be a two-stage process, according to Richard Larson (Yale Univ.) and Hans Zinnecker (MPI, Munich). A first, fragmentation, stage produces proto-stellar cores of characteristic mass a bit less than that of the Sun. These proceed to become garden-variety, low-mass stars. But many of the cores are surrounded by disks of varying mass and it is accretion from these that produces rarer, high-mass stars, in a power-law distribution ($N \propto M^{-2}$–$M^{-2.5}$, typically). While the disks are present, the protostars have stronger gravitational (tidal) interactions than they will at later stages, and Larson suggested that this is likely to be important for understanding formation of binary stars, ejection of runaway stars from clusters, and other dynamical processes.

The dichotomy between high- and low-mass star formation shows up in several ways. Massive pre-main-sequence stars are more strongly clustered than low mass ones, according to separate infrared and radio mapping studies by C. Eiroa (Observatorio Astronomico-Ign., Madrid) and Eric Keto (Lawrence Livermore National Laboratory). The disks remain in evidence for about $10^6$ yr around low-mass stars (Anneila Sargent, California Institute of Technology) but only $10^4$ yr around high mass ones (Keto). At the stage probed by Sargent's 1-mm continuum emission studies, the disks quite often have masses (0.001–0.1 $M_\odot$) and velocity structures (keplerian) much like the disk that is thought to have produced our own Solar System, suggesting that such planetary systems ought to be common.

Starting almost immediately after their formation, stars begin returning gas and energy to the ISM in winds, bipolar outflows and so forth, followed eventually by superwinds, planetary nebulae and supernova ejecta. But this is another comparably long story and will have to be told elsewhere. ☐

*Virginia Trimble is Professor of Physics at the University of California, Irvine, California 92717 and Visiting Professor of Astronomy at the University of Maryland, College Park, Maryland 20742, USA.*

---

# Origins of full-scale agriculture

THE harvesting of crops using replicas of ancient sickle-blades from the Near East, and comparison of the resulting wear on the replicas with that on the original blades, suggest that early soil tillage and plant cultivation began as long ago as the eleventh millennium BC. Romana Unger-Hamilton, now reports[1-3] her investigations of the lustred flint sickle-blades found commonly at some sites in the Near East.

R. Unger-Hamilton

Wild cereal on Mount Carmel.

She used almost 300 experimental flint blades of various kinds to harvest different species of the wild and cultivated plants common to the epipalaeolithic and neolithic sites of the Levant — wild progenitors of cereals (emmer, einkorn, barley), bread wheat and macaroni wheat, and plants growing among wild cereals, such as grasses, wild oats and vetches.

Unger-Hamilton finds that it takes about 10,000 strokes to develop a strong lustre on the blades, suggesting that the ancient blades were used for some time, perhaps as multi-purpose tools. The distribution of the polish on the blade depends on the species harvested, presumably because of the stem structure of the plant. The number of striations on the blade is also dependent on the type of ground in which the plant grows. The striations are caused by loose soil trapped at the base of the stems rather than by the plant itself. When the plants are cut close to the ground, the soil comes between blade and stem, so the side of the blade turned towards the ground becomes more striated. This last observation supports the findings of Korobkova[4], who first attributed microscopic striations on flint blades used to harvest crops to contact with soil loosened by tillage.

Unger-Hamilton's striations are particularly numerous on blades used to harvest macaroni wheat at Jericho, where weeds tend to trap the dust, compared with only one or two striations on blades used to harvest plants from a grassy cover, even after thousands of strokes at the base of the plants. These data can be compared with those on ancient flint blades from the southern Levant, dated to the natufian period (10,000–8,000 BC), and from Jericho in the early neolithic (8,000–6,000 BC). Only about a quarter of the natufian blades were heavily striated, compared with about half from the beginning of the early neolithic and three-quarters towards the end. Unger-Hamilton concludes that most of these blades were used to harvest cereal plants close to the ground, including the stem, during the early natufian, but that the degree of loose earth increased with time, indicating a change in harvesting from tilled soil. Although other factors may have been involved, Unger-Hamilton interprets her data to show that full-scale agriculture in the southern Levant began in the second phase of the early neolithic, about 7,000 BC, and that cultivation of cereals began in the early natufian, in the eleventh millennium BC. Paul G. Bahn

***Paul G. Bahn is a freelance writer on archaeology at 428 Anlaby Road, Hull HU3 6QP, UK.***

1. Unger-Hamilton, R. *World Arch.* 17, 121 (1985).
2. Unger-Hamilton, R. *Method in Microwear Analysis* (BAR Int. Ser. No. 435, Oxford, 1988).
3. Unger-Hamilton, R. *Curr. Anth.* 30, 88 (1989).
4. Korobkova, G.F. in *The Bronze Age Civilization of Central Asia* (ed. Kohl, P.L.) 325 (Sharpe, New York, 1981).